

AD _____

Award Number: DAMD17-98-1-8472

TITLE: Isolation of Novel Prostate Cancer Tumor Suppressor Genes
in African American and Caucasian Men thru Laser
Microdissection and Representational Difference Analysis

PRINCIPAL INVESTIGATOR: G. Steven Bova, M.D.

CONTRACTING ORGANIZATION: Johns Hopkins University School of Medicine
Baltimore, Maryland 21205-2196

REPORT DATE: March 2001

TYPE OF REPORT: Final

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for Public Release;
Distribution Unlimited

The views, opinions and/or findings contained in this report are
those of the author(s) and should not be construed as an official
Department of the Army position, policy or decision unless so
designated by other documentation.

20010925 147

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 074-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE March 2001	3. REPORT TYPE AND DATES COVERED Final (15 Aug 98 - 14 Feb 01)		
4. TITLE AND SUBTITLE Isolation of Novel Prostate Cancer Tumor Suppressor Genes in African American and Caucasian Men thru Laser Microdissection and Representational Difference Analysis		5. FUNDING NUMBERS DAMD17-98-1-8472		
6. AUTHOR(S) G. Steven Bova, M.D.				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Johns Hopkins University School of Medicine Baltimore, Maryland 21205-2196 E-Mail: gbov@jhmi.edu		8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Materiel Command Fort Detrick, Maryland 21702-5012		10. SPONSORING / MONITORING AGENCY REPORT NUMBER		
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 Words) We used RDA to identify homozygously deleted DNA clones within metastatic prostate cancer xenograft DNA, and found that all of the homozygously deleted clones mapped to a single region of chromosome 12p. We confirmed that the metastatic lesions from this patient also contained this homozygous deletion, and then analyzed this region in a series of 41 metastatic tumors from 19 patients, where we found that 50% of patients' tumors show loss. This 12p deletion occurs with similar frequency in caucasians and african-americans based on our small sample. We mapped this genomic region, and found that two previously identified potential candidate genes ETV(tel) and CDKN1B(p27) are located there. Analysis of these genes has revealed no sequence changes consistent with an important tumor suppressor role. Extensive analysis of p27 for possible mutational or methylation changes was negative. Major observations from our work include the finding of a homozygous deletion on chromosome 12p in metastatic prostate cancer, considered to be a major indicator that an important gene is nearby on chromosome 12p. Further analysis of this region revealed unexpected high degree of allelic loss in this region. Specific genes in the region were analyzed, and p27 appears to be the likely target, inactivated by loss of one copy. Further analysis was curtailed due to lack of funding.				
14. SUBJECT TERMS prostate cancer, representational difference analysis			15. NUMBER OF PAGES 23	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	

Table of Contents

Cover.....	
SF 298.....	
Table of Contents.....	
Introduction.....	3
Body.....	3
Key Research Accomplishments.....	5
Reportable Outcomes.....	5
Conclusions.....	5
References.....	5
Appendices.....	

Introduction:

In order to better understand prostate cancer in Caucasians and African-Americans, we used Representational Difference Analysis to identify novel genes important in the development of prostate cancer. We identified a region of homozygous deletion, and analyzed genes in this chromosomal region.

Report Body

Original Statement of Work Item	Progress to Date
1. Obtain pure metastatic prostate cancer tissue from a diverse group of patients suitable for molecular analysis	Metastatic samples from 27 consented patients now available, including 5 african-americans, and 1 hispanic. Support for additional 23 patients requested in Phase II, specifically targeting the african-american population
2. Obtain 10 micrograms of 95-99% pure metastatic prostate cancer DNA from 2-6 patients who died of metastatic prostate cancer	Completed in 10 patients
3. Perform RDA on each of 2-6 samples. Identify homozygously deleted amplimers in each tumor	RDA completed and published in 1 patient sample so far. Analysis of positive RDA results in this first sample led to extensive 12p studies to fully evaluate region.
4. Confirm homozygous deletion of each amplimer in the patient from which it was isolated	Completed and published.
5. Prioritize amplimers for further analysis by analysis in a panel of 41 metastatic prostate cancers	Completed and published.
6. Sequence highest priority amplimers	Completed and in press for TEL and p27 genes
7. Identify BACs (or YACs) containing the highest priority amplicons. Determine size of individual homozygous deletions	Will be performed if methylation analysis of p27/TEL is negative. This work should be simplified in future cases if human genome sequence available.
8. Identify genes within regions less than 500 kb in size. Analyze specific genes within these regions for alteration	Completed and published for p27 and TEL. Further analysis of p27 completed and manuscript in preparation.

Specific Aim 1: We found that obtaining sufficient quantities of DNA from LCM to be excessively time consuming using the current technology. Nonetheless, we found that careful cryostat dissection provides samples of sufficient quantity and quality for RDA, as evidenced by our success in Specific Aims 2 and 3. A detailed description of the samples used is contained in the published account of this work^{1,2}.

Specific Aim 2: Using representational difference analysis, we identified and confirmed the presence of a homozygously deleted region on chromosome 12p in prostate cancer (Fig 1)^{1,2}. This is the first homozygous deletion identified in this region in prostate cancer, and represents the first successful application of RDA technology in prostate cancer that we are aware of. These results support our hypothesis that RDA can be performed in prostate cancer DNA samples to identify regions of homozygous deletion. The time required for the RDA process and subsequent extensive work required in Specific Aim 3 to further characterize this homozygous deletion was more time consuming than we anticipated, and prevented us from performing RDA in another case.

Progress on Specific Aim 3: Examination of the homozygously deleted region in a series of primary and metastatic prostate cancers demonstrated previously undetected loss of heterozygosity in this region in 50% of metastatic prostate cancers, as detailed in our publications (Fig 2)^{1,3,2} and in Table 1 below. There

appears to be no difference in the rate of loss of heterozygosity in this region in Caucasians and African-Americans, suggesting that both populations are affected by a putative important molecular alteration in this region. This finding supports our hypothesis that homozygous deletions are markers of important genomic instability in prostate cancer. Candidate genes within the region include genes ETV(tel) and CDKN1B(p27). Recently published immunostaining studies show decreased expression of p27 correlating with degree of de-differentiation in prostatic intraepithelial neoplasia, primary cancer, and metastatic prostate cancer, consistent with possible dysfunction of p27 in these cells, but this gene product has not proven useful so far as an independent predictor of prognosis ^{4,5}. A conformational polymorphism and sequencing analysis study appeared to rule out ⁶ mutation as a mechanism for inactivation of this gene product. Subsequent mutational and methylation analysis of p27 revealed no significant evidence of alteration of this type. Without additional funds to pursue the research, our conclusion at this point is that haploinsufficiency of p27 due to deletion may be a significant event in prostate cancer etiology and/or progression.

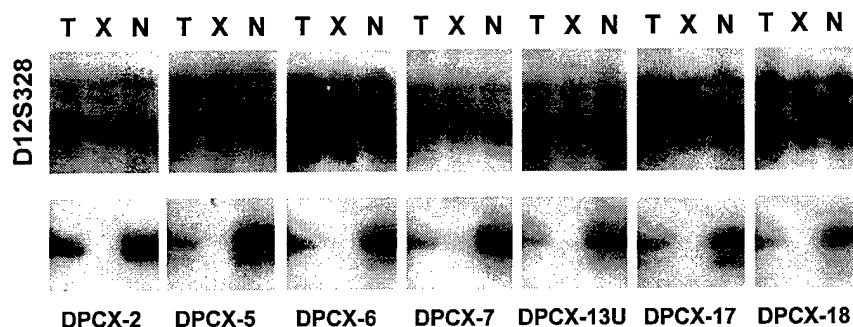


Figure 1: Multiplex PCR illustrating homozygous deletion of 7 RDA amplicons in human prostate cancer Xenograft (X) DNA and in 95% pure tumor DNA isolated directly from tissue from the same patient (faint signal due to residual noncancer cells). Equal amount of Noncancerous (N) DNA from the same patient shows equal or higher amplification under the same conditions.

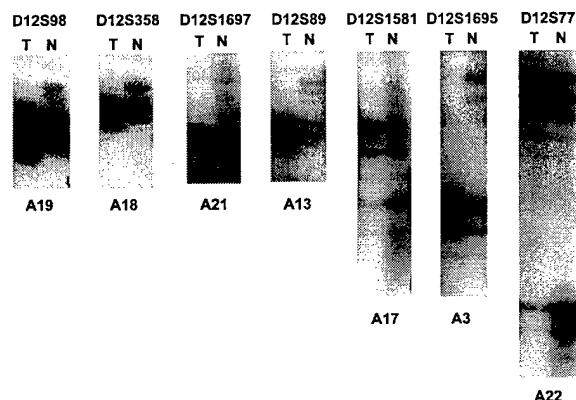


Figure 2: Loss of heterozygosity in region in metastatic prostate cancer DNA from seven patients at various microsatellite loci within the region of the 12p homozygous deletion. Metastatic Tumor (T) DNA shows complete or near complete absence of signal from one of two alleles compared to alleles amplified in noncancerous (N) DNA from the same patients, consistent with hemizygous loss of this region in the tumors.

Table I – High-resolution deletion mapping of chromosome 12p12-13 in nine cases demonstrating LOH. L=LOH, N=non-informative, and R=retained. * indicates that marker was homozygously deleted in xenograft. Region in bold is minimal region in these samples demonstrating overlapping LOH.

Locus Name	Distance from centromer (cM)	Individual Patients with LOH at 12p12-13								
		A2	A3	A8	A13	A17	A18	A19	A21	A22
D12S1695	21.3	N	L	R	L	N	L	N	L	N
D12S77	21.8	L	L	R	L	L	N	N	L	L
D12S89*	24.6	N	L	R	L	N	L	L	L	L
D12S98*	25.6	R	L	N	L	L	L	L	N	L
D12S1697*	25.6	R	L	R	L	L	L	L	L	L
D12S358	27.2	N	N	L	N	L	L	R	N	L
D12S1581	30.8	R	L	L	L	L	L	R	N	L

Key Research Accomplishments

- **Identified a homozygous deletion in a prostate cancer, considered to be highly indicative of important gene alteration within this region**
- **Mapped this homozygous deletion region**
- **Identified Loss of Heterozygosity in this region in a large percentage of prostate cancers**
- **Examined genes within this region**
- **Identified p27 as the most likely important altered gene in this region**
- **Identified haploinsufficiency as the most likely mechanism for p27's role in prostate cancer**

Reportable Outcomes

- Identification and publication of a small focused region of homozygous deletion on chromosome 12p in metastatic prostate cancer ¹.
- Identification and publication of loss of heterozygosity in this region in 50% of tumors ².
- Presentation of these findings at the Cold Spring Harbor biennial tumor suppressor genes meeting (1998), at the AACR meeting (1998,1999), and at the American Urological Association meeting (1998).
- Analysis and publication (in press) of candidate genes CDKN1B(p27) and ETV(tel) in this region ⁶.
- Continuing work in this region: promoter methylation analysis.
- Development of a Clinician/Scientist: Dr. Adam Kibel performed the laboratory work specified in the original grant proposal while serving as a postdoctoral research fellow serving in the P.I. and in Dr. W. B. Isaacs' laboratory. Partly as a result of the successful completion of this project, Dr. Kibel is a new faculty member in the Division of Urology at Washington University in St. Louis. Dr. Kibel plans to apply for separate funding to continue work in the 12p region in collaboration with the PELICAN lab.
- Mutational and Methylation analysis of p27 submitted for publication⁷.

Conclusions

We painstakingly identified a novel region of frequent genetic alteration in prostate cancer, which affects both Caucasians and African-Americans. We identified genes within this region. We identified the most likely gene target in this region: p27, and identified the probable mechanism for its action in prostate cancer: haploinsufficiency. Further work is needed but our application for additional funding was denied.

Reference List

1. Kibel, A. S., Schutte, M., Kern, S. E., Isaacs, W. B., and Bova, G. S. Identification of 12p as a region of frequent deletion in advanced prostate cancer. *Cancer Res.*, **58**: 5652-5655, 1998.
2. Kibel, A. S., Freije, D., Isaacs, W. B., and Bova, G. S. Deletion mapping at 12p12-13 in metastatic prostate cancer. *Genes Chromosomes.Cancer*, **25**: 270-276, 1999.
3. Kibel, A. S., Faith, D. A., Bova, G. S., and Isaacs, W. B. Loss of heterozygosity at 12P12-13 in primary and metastatic prostate adenocarcinoma. *J.Urol.*, **164**: 192-196, 2000.

4. Erdamar, S., Yang, G., Harper, J. W., Lu, X., Kattan, M. W., Thompson, T. C., and Wheeler, T. M. Levels of expression of p27KIP1 protein in human prostate and prostate cancer: an immunohistochemical analysis. *Mod.Pathol.*, 12: 751-755, 1999.
5. Guo, Y., Sklar, G. N., Borkowski, A., and Kyprianou, N. Loss of the cyclin-dependent kinase inhibitor p27(Kip1) protein in human prostate cancer correlates with tumor grade. *Clin.Cancer Res.*, 3: 2269-2274, 1997.
6. Kibel, A., Faith, D. A., Nelson, J. B., Pretlow, T. G., Vessella, R. L., Sawyers, C. L., Bova, G. S., and Isaacs, W. B. Mutational Analysis of CDKN1B and ETV6 in Prostate Carcinoma. Submitted, 2000.
7. Adam S. Kibel[§], Mathew Christopher[§], Dennis A. Faith^{*}, G. Steven Bova^{*‡}, Paul J. Goodfellow[§], and William B. Isaacs^{*}. Methylation and Mutational Analysis of p27^{kip1} in Prostate Carcinoma. Manuscript in preparation

Identification of 12p as a Region of Frequent Deletion in Advanced Prostate Cancer¹

Adam S. Kibel,² Mieke Schutte, Scott E. Kern, William B. Isaacs, and G. Steven Bova

Departments of Urology [A. S. K., W. B. I., G. S. B.], Pathology [G. S. B.], and Oncology [S. E. K., W. B. I., G. S. B.], The Johns Hopkins Medical Institutions, Baltimore, Maryland 21287, and Division of Endocrine Oncology, Department of Medical Oncology, Rotterdam Cancer Institute (Daniel den Hoed Kliniek), Academic Hospital Rotterdam, Rotterdam, the Netherlands [M. S.]

Abstract

The identification of homozygous deletions in malignant tissue has been a powerful tool for the localization of tumor suppressor genes. Representational difference analysis (RDA) uses selective hybridization and the PCR to isolate regions of chromosomal loss and has facilitated the identification of tumor suppressor genes such as *BRCA2* and *PTEN*. Twenty RDA clones were generated by comparing genomic DNA from a prostate cancer xenograft to the same patient's normal kidney DNA. Southern blot analysis of the tester and driver and of normal and xenograft DNA, using the differential products as probes, showed the homozygous deletion in 16 of 20 RDA clones. The sequence of one of the differential products overlapped HSU59962, a genomic GenBank sequence on chromosome 12p12-13. Multiplex PCR of the xenograft DNA using polymorphic repeats mapped the deletion to a 1-5-cM region on 12p. Genomic DNA isolated from a panel of cryostat microdissected metastatic prostate adenocarcinomas/normal pairs was screened for loss of heterozygosity using the same polymorphic repeats. Loss of heterozygosity was demonstrated in 9 (47%) of 19 patients. This region may contain, or lie in close proximity to, tumor suppressor genes important in the progression and/or initiation of prostate cancer.

Introduction

The deletion of genomic DNA is a common feature of neoplastic cells. Loss of these regions can inactivate tumor suppressor genes important in the initiation and progression of malignancy. LOH³ analysis has been useful in identifying regions of interest within the genome but has been of limited use in the cloning of novel candidate tumor suppressor genes. This has been true for malignancies in general and specifically for prostate cancer. Losses of 6q, 8p, 8q, 10p, 10q, 13q, 16q, 17p, 18q, and 19p have all been implicated in prostate cancer (1-6). However, to date no LOH study has led to cloning a gene important in prostate carcinoma, in part because of the many limitations of allelic loss studies (7).

In contrast, identification of homozygous deletions in malignant tissue has been strongly associated with the presence of suppressor gene loci (8). *RB* (9) and *PTEN* (10) are two examples of tumor suppressor genes that were identified at least partly through the recognition of homozygous deletion of these genes in various cancerous tissues or cell lines. Three homozygous deletions have been described in prostate cancer. Morton *et al.* (11) described a homozygous deletion in the prostate cancer cell line PC-3 of the α -catenin gene. This protein helps mediate cell-cell adhesion through the E-

cadherin protein complex. Abnormalities in this pathway have been implicated in high grade and stage disease (12). The recently cloned *PTEN* gene is homozygously deleted in two prostate cancer cell lines (10) and is frequently altered in advanced prostate cancer (13). A third homozygous deletion at 8p22 was described by Bova *et al.* (1) in a region frequently demonstrating LOH. A gene, *N33*, was identified within the deletion but found to be normally expressed and not mutated in prostate cancer cell lines (14). At this time, this gene does not appear to play a role in prostate cancer.

RDA (15) is a method for isolating DNA fragments that are present in only one of two nearly identical genomes. The DNA is size-selected to simplify the genome and then undergoes subtractive hybridization followed by PCR amplification of genomic fragments found differentially in the two genomes. By comparing normal to malignant DNA from the same patient, homozygous deletions can be identified. Use of this technique has facilitated the identification of two tumor suppressor genes to date, *BRCA2* (16) and *PTEN* (10). We report the use of RDA in a prostate cancer xenograft to identify a novel homozygous deletion.

Materials and Methods

Autopsy DNA. Prostate cancer tissue was obtained from 19 patients with metastatic prostate cancer undergoing autopsy between January 1995 and June 1997. All of the patients had undergone androgen-deprivation therapy and died from complications of metastatic disease. DNA was extracted from normal and malignant tissue samples as described previously (1). Institutional Review Board-approved informed consent was obtained from patients and family.

Immunohistochemistry. PSA immunohistochemistry on xenograft tissue sections was performed using standard automated techniques (Ventana Medical Systems, Lake Success, NY) with Chemicon (Temecula, CA) rabbit antihuman PSA polyclonal antiserum at 1:500 dilution as the primary antibody, and biotinylated goat antirabbit monoclonal secondary antibody (Ventana Medical Systems). Staining was performed with peroxidase-based chromogen (diaminobenzidine) detection. Slides were examined using standard light microscopy with cytoplasmic and intraglandular brown pigment deposition indicative of the presence of PSA. Intratumoral connective tissue cells and tumor nuclei served as internal negative controls.

Tumor DNA Isolation and Extraction. A prostate cancer metastasis of the rib was harvested at autopsy from a 55-year-old male with metastatic, androgen-deprived prostate carcinoma. The tissue was minced and placed s.c. in male severe combined immunodeficient mice. After two passages, the xenograft was harvested. Genomic DNA from this xenograft was extracted as described previously (1).

RDA. RDA was performed as described previously (15) with two exceptions, both described by Schutte *et al.* (16): (a) the hybridization times were increased to 40 h to account for the increased genomic complexity of the xenograft; and (b) during the PCR amplification of the hybridized DNA, the Taq polymerase is added after a 3-min incubation at 85°C. This step reduces priming mediated by duplexes of near-identical repetitive elements. After three rounds of hybridization and PCR amplification, differential products could be visualized by gel electrophoresis.

Cloning. The differential products were ligated into pBluescript II plasmid vector (Stratagene, Menasha, WI) using T4 ligase and transformed into competent bacteria according to the manufacturer's instructions. Clones were grown on Luria-Bertani medium/ampicillin plates. Transformed colonies were selected and grown in 10 ml of Luria-Bertani media, and the plasmids (DPCX-

Received 7/29/98; accepted 10/27/98.

The costs of publication of this article were defrayed in part by the payment of page charges. This article must therefore be hereby marked advertisement in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.

¹ A. S. K. is an American Foundation of Urologic Disease Scholar. In addition, this work was supported by American Cancer Society Grant 58-005-39-IRG (to A. S. K.); Dutch Cancer Society KWF Grant DDHK 97-1644 (to M. S.); Specialized Programs of Research Excellence Grants CA 62924 (to S. E. K.) and CA 58236 (to W. B. I.); and by CaPCURE, National Cancer Institute Grants CA 58236 and CA 59457 (to G. S. B.).

² To whom requests for reprints should be addressed, at The Johns Hopkins Hospital, James Buchanan Brady Urological Institute, Marburg 105, 600 North Wolfe Street, Baltimore, MD 21287-2101.

³ The abbreviations used are: LOH, loss of heterozygosity; RDA, representational difference analysis; PSA, prostate-specific antigen.

1–20) were extracted using Wizard Plus Minipreps (Promega, Madison, WI). One μg of each DPCX plasmid was digested with 1 unit of *Bam*HI at 37°C for 1 h, and the digest was resolved on a 1.5% low-melting-point agarose gel. The inserts were extracted from the gel using QIAquick Gel Extraction Kit according to the manufacturer's instructions (Qiagen, Santa Clarita, CA).

Southern Blot Analysis. Five μg of tester and driver or xenograft and kidney DNA were run in parallel lanes on a 2% agarose gel, transferred to Hybond-N membrane (Amersham, Arlington Heights, IL) in 0.4 M NaOH-0.6 M NaCl, and then covalently linked to the membrane with UV radiation (Stratagene). The DPCX inserts were labeled with [α (32)P]dCTP using the Multiprime DNA labeling system (Amersham) according to the manufacturer's instructions. Probes were boiled with 0.5 ml of 2-mg/ml sonicated salmon sperm DNA, cooled on ice, and then hybridized overnight at 64°C in Rapid-hyb buffer (Amersham). The blots were then washed in 15 mM NaCl, 1 mM NaH_2PO_4 , 0.1 mM EDTA, and 0.5% SDS (pH 7.4) at 64°C and then autoradiographed. Blots were reprobbed with inserts that were not deleted to demonstrate that equal quantities of DNA were present on each blot.

Sequencing. Plasmids that contained confirmed homozygous deletions were then sequenced using the fluorescent dideoxy terminator method of sequencing on a Perkin-Elmer, Applied Biosystems Division (Foster City, CA) 377 automated DNA sequencer, following standard protocols (17).

Multiplex PCR Amplification. Primers were designed for each DPCX fragment and purchased from Biosynthesis (Lewisville, TX) as follows: (a) DPCX-2, 5'-CTAACGAGAACGCTGGCTAAC-3' and 5'-CCCCAAACACTGCTCAG-3'; (b) DPCX-5, 5'-AAATCTGGGGGAAAGCAAAGC-3' and 5'-GGCCC-AGGATCAGTTCAATG-3'; (c) DPCX-6, 5'-TAAATCTGGGGGAAAGCAAAG-3' and 5'-GCCGGGATCAGTTCAATG-3'; (d) DPCX-7, 5'-GCCCA-GGATCAGTTCAATG-3' and 5'-GGAAAGGGCAGAAAAAGAGAC-3'; (e) DPCX-13U, 5'-CCTTCATCCGGACITGATTTC-3' and 5'-GCACAGCGTC-GTCTTGTC-3'; (f) DPCX-17, 5'-CACGGGCATATACCTGGCTAA-3' and 5'-GAATCTGGGGGAAAGCAAAG-3'; and (g) DPCX-18, 5'-CTITCCCCCA-GATTTAGTCTC-3' and 5'-GCATAGTAGGCGGTCTGTG-3'.

Primers in the region of DPCX-2 (D12S1695, D12S77, D12S89, D12S1967, D12S98, D12S358, and D12S1581) and control primers (D13S328 and D8S549) were purchased from Research Genetics (Huntsville, AL). PCR amplification using these primers was used to create a map of the homozygous deletion and of the region of maximum LOH using the genomic map available from Genethon (18). Six μl of F primer (20 μM) was end-labeled with 3 μl

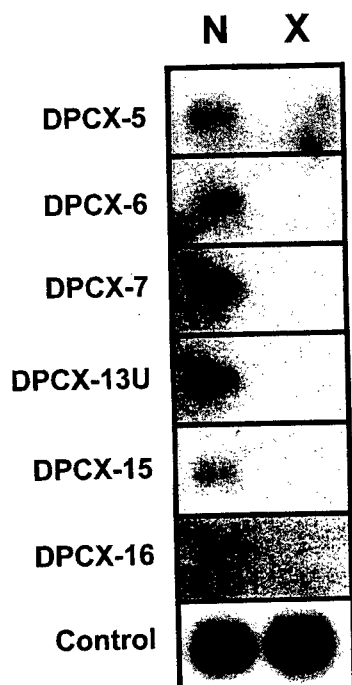


Fig. 1. Southern blot analysis of DPCX inserts. Identical blots were probed and DPCX-5, -6, -7, -13U, -15, and -16 were found to be homozygously deleted. Control demonstrates that equal amounts of DNA are present on each blot. N, noncancerous kidney DNA; X, xenograft DNA.

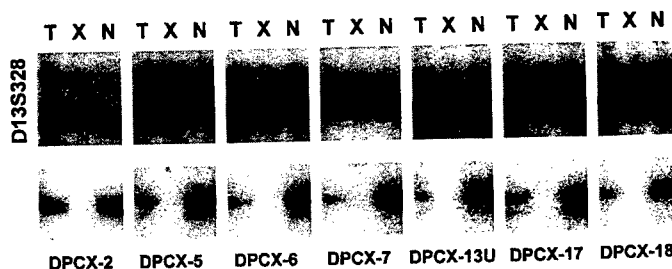


Fig. 2. Multiplex PCR of noncancerous (N), xenograft (X), and liver metastasis (T) templates using primers designed from DPCX insert sequence and using D13S328 as the control. Lanes X (containing xenograft template) demonstrate normal amplification of D13S328 and no amplification of DPCX insert. Lanes T (containing tumor template) demonstrate decreased amplification compared with control Lanes N (noncancerous template).

[$\gamma^{32}\text{P}$]ATP (ICN Radiochemicals, Irvine CA) using 20 units of T4 kinase (Life Technologies). Reaction mixture was incubated at 37°C for 1 h. The enzyme was inactivated by incubation at 68°C for 20 min.

Genomic DNA (50 ng) underwent PCR amplification in 10 mM Tris-HCl, 50 mM KCl (pH 8.3), 1.5–3.5 mM MgCl_2 , 1 unit Taq DNA polymerase, 15 mM dNTP, and 80 nM of labeled F primer and unlabeled R primer. Amplified PCR fragments were denatured at 94°C for 5 min and cooled on ice. Then 2 μl of each sample was separated by polyacrylamide urea gel electrophoresis and autoradiographed. Allelic imbalances were considered to be allelic losses if by visual estimation a 50% or greater signal reduction was seen for a tumor allele as compared with the normalized retained noncancerous counterpart. To confirm homozygous deletions, reactions were repeated under identical conditions except multiplexed with markers ($\gamma^{32}\text{P}$ -labeled D13S328 or D8S549) known to be rarely homozygously deleted⁴. These markers served as an additional control for variations in DNA template concentration.

Results

Histological analysis of the second-passage xenograft demonstrated gland formation morphologically consistent with metastatic prostate adenocarcinoma. Intraluminal and intracytoplasmic expression of PSA was demonstrated by immunohistochemistry, again consistent with prostatic origin. After three rounds of RDA, differential products were visualized on an agarose gel and cloned into pBluescript II. Southern blot analysis of the tester *versus* driver blots revealed that 16 of the 20 clones were present in the tester but not in the driver DNA. Similar analysis of the remaining 16 probes on xenograft/normal DNA blots confirmed the homozygous deletion of 13 probes (Fig. 1), whereas 3 probes—DPCX-1, -3, and -13L—were only hemizygotously deleted. To demonstrate that the decrease in signal intensity was not an artifact of DNA concentrations, DPCX-9 (an RDA clone which was not deleted as demonstrated by Southern blot analysis) was used as a probe (Fig. 1). Sequencing revealed that DPCX-2 was identical to DPCX-4, -10, -15, and -19 and that DPCX-17 was identical to DPCX-14U. Thus, eight independent fragments were cloned from areas of homozygous deletion.

Multiplex PCR amplification, using D13S328 as a control, confirmed that DPCX-2, -5, -6, -7, -13U, -17, and -18 were homozygously deleted in the xenograft compared with normal DNA from the same patient (Fig. 2). DNA extracted from a liver metastasis from the same patient demonstrated decreased PCR amplification compared with noncancerous DNA (Fig. 2), which was consistent with the presence of a homozygous deletion partially obscured by residual noncancerous DNA present in the sample.

The sequences for DPCX-2 and DPCX-16 both mapped to different regions of HSU59962, a genomic GenBank sequence on chromosome 12p12–13. PCR of DNA from the Coriell National Institute of General Medical Sciences human/rodent somatic cell hybrid library (Camden,

⁴ G. S. Bova and W. B. Isaacs, unpublished data.

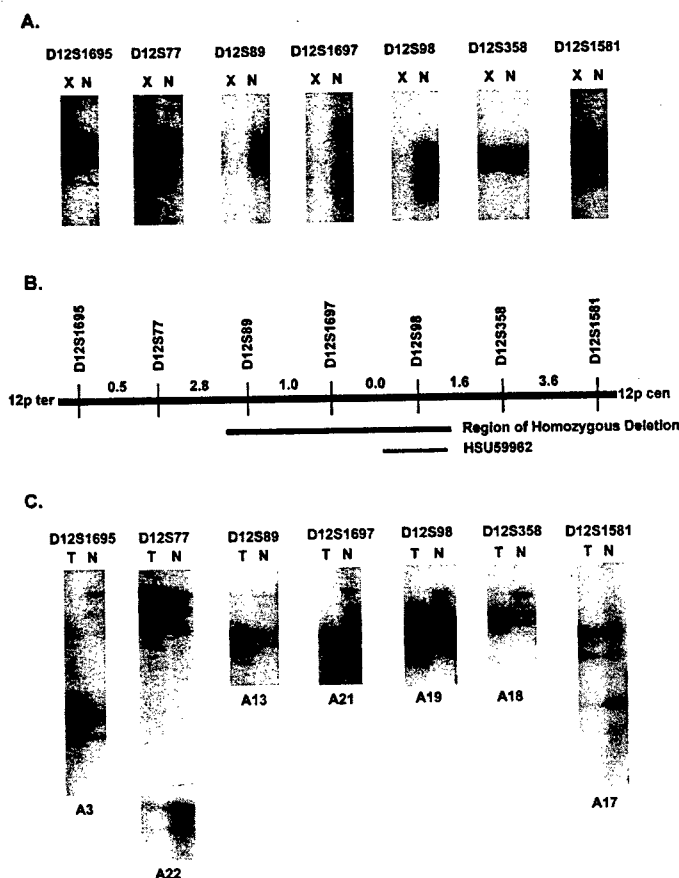


Fig. 3. Mapping of homozygous deletion by PCR analysis. A, polymorphic markers D12S89, D12S1697, and D12S98 are homozygously deleted and D12S1581, D12S77, D12S358, and D12S1695 are not. To confirm the deletion, homozygously deleted markers were rerun multiplexed with D12S358 or D12S549 (data not shown). B, line drawing of the deleted region on a genomic map. Distances between polymorphic markers are given in cM. C, microsatellite analysis of 12p12-13 using the same polymorphic markers. Specimens are from seven different patients. X, xenograft template DNA; T, tumor template DNA; N, noncancerous template DNA.

NJ) demonstrated that all of the homozygously deleted sequences were located on chromosome 12.

Polymorphic markers located within and flanking HSU59962 on a genomic map described by Dib *et al.* (16) demonstrated that D12S89, D12S1697, and D12S98 were homozygously deleted from the xenograft, whereas flanking markers D12S1695, D12S77, D12S358, and D12S1581 were not. Reactions were then repeated using multiplexed PCR to provide a positive control in each PCR reaction (Fig. 3A). This established the boundaries of the deletion at D12S77 and D12S358 and the deletion size at 1 to 5 cM. (Fig. 3B).

The same polymorphic markers were used to analyze 19 tumor/normal pairs: highly purified paired genomic samples derived from metastatic

prostate cancer tissue and noncancerous DNA obtained at autopsy from 19 patients. Nine (47%) of the nineteen demonstrated LOH in this region (Fig. 3C). The overlapping region of LOH was similar to the homozygous deletion, and the frequency of allelic loss was highest in markers homozygously deleted in the xenograft (Table 1).

Discussion

An approach to identifying candidate tumor suppressor genes is to identify homozygous deletions of genomic DNA within tumors. RDA has recently proven to be useful in facilitating identification of these regions. The *PTEN* gene was recently isolated by performing RDA on human breast cancer cells. A homozygously deleted region was identified at 10q23. Subsequent analysis revealed this deletion contained the *PTEN* gene and that it was frequently deleted in breast, brain, and prostate cancer (10). A similar experimental design was used by Schutte *et al.* in which the analysis of a pancreatic cancer xenograft demonstrated a homozygous deletion at 13q12.3 in the region of *BRCA-2* (16).

Data presented here suggest the presence of a previously unknown prostate cancer tumor suppressor locus. The region was identified by RDA and confirmed by Southern analysis and multiplex PCR. Using the National Center for Biotechnology Information data base, the Coriell National Institute of General Medical Sciences human/rodent somatic cell hybrid panel, and polymorphic primers located in the area of the deletion, we have mapped the deletion of a 1-5-cM region of 12p. Multiplex PCR amplification of DNA isolated from a liver metastasis from the same patient demonstrated decreased PCR amplification compared to the noncancerous DNA (Fig. 2), which is consistent with a homozygous or hemizygous deletion in this region. The small amount of amplification may be attributable to normal cells within the metastatic tumor deposit.

To further support our conclusion that this region contains a gene(s) important in prostate cancer, we examined purified DNA samples obtained from metastatic deposits from 19 patients with androgen-deprived prostate cancer. Forty-seven percent of the metastatic lesions demonstrated LOH in this region.

Previous studies have not detected 12p abnormalities in prostate cancer. Comparative genomic hybridization has been used in two large studies to examine genetic changes in prostate cancer. Visakorpi *et al.* (6) examined 31 primary and 9 locally recurrent prostate carcinomas. The regions of most frequent copy number loss were 8p(32%), 13q(32%), 6q(22%), 16q(19%), 18q(19%), and 9p(16%). Cher *et al.* (5) were the first to use comparative genomic hybridization to study metastatic prostate cancers. In their study, copy loss was noted in 8p(80%), 13q(75%), 16q(55%), 17p(50%), and 10q(50%).

Several groups have examined localized and metastatic prostate cancer for LOH. Carter *et al.* (2) used Southern blot analysis to examine 17 polymorphic markers on 11 different chromosomal arms in 28 localized and 4 metastatic lesions. Twenty-nine and 31% demonstrated LOH at 10q and 16q, respectively. In this study, 12p was not

Table 1. Informativeness of microsatellite markers in all of the 19 patients studied and high-resolution deletion mapping of chromosome 12p 12-13 in 9 cases demonstrating LOH. Region in boldface is minimal region in these samples demonstrating overlapping LOH.

Locus name	Allelic loss/Informative cases (%)	Individual patients with LOH at 12p 12-13								
		A2	A3	A8	A13	A17	A18	A19	A21	A22
D12S1695	4/11 (36%)	N ^a	L	R	L	N	L	N	L	N
D12S77	6/16 (38%)	L	L	R	L	L	N	N	L	L
D12S89 ^b	6/15 (40%)	N	L	R	L	N	L	L	L	L
D12S98 ^b	6/14 (43%)	R	L	N	L	L	L	L	N	L
D12S1697 ^b	8/16 (50%)	R	L	R	L	L	L	L	L	L
D12S358	5/12 (41%)	N	N	L	N	L	L	R	N	L
D12S1581	6/14 (43%)	R	L	L	L	L	L	R	N	L

^a N, noninformative; L, LOH; R, retained.

^b Marker was homozygously deleted in xenograft.

examined. A second study, by Kunimi *et al.* (4), also used Southern blotting to examine 10 primary tumors, 4 cases of lymph node metastasis, and 4 cases of brain metastasis. 8p, 10p, 10q, 16q, and 18q were found to demonstrate LOH in 50, 55, 30, 60, and 43%, respectively. In this study, 12p was examined at one polymorphic marker (D12S16), the exact location of which is unknown. One brain metastasis demonstrated LOH at this marker. A third study, by Sakr *et al.* (3), examined 19 primary tumors and lymph node metastases for evidence of LOH by PCR amplification of polymorphic repeats. Markers on 8p, 10q, and 16q demonstrated LOH in 25, 12, and 8%, respectively, of metastatic samples and 29, 18, and 42%, respectively, of primary tumors. Although no LOH was detected on 12p, only one marker was examined—*F8VWF*—which is approximately 9 cM telomeric from our region of interest.

Our data demonstrating 47% LOH at 12p12–13 in metastatic prostate cancer would make this region one of the most frequently altered genomic regions in prostate cancer. Data from the published comparative genomic hybridization studies did not detect significant copy-number loss or gain at 12p despite examining the entire genome (5, 6). However, this methodology lacks the resolution of microsatellite analysis. Only two of the previous LOH studies have examined 12p. Neither examined a marker near our region of interest. Although 12p has not previously been implicated in prostate cancer, Berube *et al.* (19) did find that the microcell transfer of a portion of 12q suppressed tumorigenicity in nude mice and that the loss of the chromosomal fragment restored the malignant phenotype.

Abnormalities in 12p have been implicated in other tumor types. Sato *et al.* (20) demonstrated that 38% of ovarian cancers had allelic loss on 12p. The marker used in this study (D12S16) is not well localized on currently available genetic maps. 12p12.3 has been strongly implicated in acute lymphoblastic leukemia. Baccichet and Sinnett (21) demonstrated allelic loss of this region in 47% of the cases that they studied. The region of maximal LOH, D12S89 to D12S358, is identical to our region of interest. Lastly, abnormalities of 12p have been implicated in lung cancer. Takeuchi *et al.* (22) demonstrated LOH on 12p in 33% of non-small cell lung cancers. The region of maximal LOH was D12S269 to D12S308, which is approximately 5 cM closer to the centromere than the region that we have identified.

Genes that are believed to lie within our region of interest according to the National Center for Biotechnology Information human genome map⁵ include *microsomal glutathione S-transferase*, *NKG2-A* and *NKG2-B type II integral membrane proteins*, *translational initiation factor 2 gamma subunit*, *ETS-related protein*, *human glomerular epithelial protein 1 (GLEPP1)*, and *human epidermal growth factor receptor kinase substrate*.

It is possible that no genes of importance to tumor suppression lie within the region of 12p identified here. Although the fact that 47% of our tumors demonstrated LOH at 12p12–13 provides strong supportive evidence of a tumor suppressor gene at this site, we note that another site of a homozygous deletion (8p22) also frequently demonstrates LOH, and no prostatic tumor suppressor gene has been identified at that site to date (14). It is also important to recognize that the source of this xenograft and the metastatic foci examined for LOH were metastatic androgen-deprived tumors. These tumor foci likely underwent multiple damaging genetic events before and after metastasis, only some of which are critical to the tumor phenotype. However, the fact that the deletion was found in DNA isolated both from the xenograft and from a liver metastasis from the same patient is consistent with the hypothesis that the deletion of this region was present before metastasis. Taken together, the data are strongly suggestive that inactivation of a tumor suppressor gene located

within this region could be responsible for initiation, metastasis, or progression to androgen independence in prostate cancer.

Conclusion. In conclusion, by using RDA we have identified a novel homozygous deletion at 12p12–13 in a metastatic prostate cancer xenograft. A high percentage of cryostat microdissected metastatic prostate tumors demonstrate LOH in this region. This region has not been previously implicated in prostate cancer but has been implicated in other malignancies. This region may contain, or lie in close proximity to, tumor suppressor genes important in the progression and/or initiation of metastatic prostate cancer.

Acknowledgments

We thank Mario Eisenberger, Michael Carducci, Pendleton Powers, and Victoria Sinibaldi for clinical assistance and John T. Isaacs, John Lamb, Charles M. Ewing, and John Robinson for technical assistance.

References

1. Bova, G. S., Carter, B. S., Bussemakers, M. J., Emi, M., Fujiwara, Y., Kyprianou, N., Jacobs, S. C., Robinson, J. C., Epstein, J. I., Walsh, P. C., and Isaacs, W. B. Homozygous deletion and frequent allelic loss of chromosome 8p22 loci in human prostate cancer. *Cancer Res.*, 53: 3869–3873, 1993.
2. Carter, B. S., Ewing, C. M., Ward, W. S., Treiger, B. F., Aalders, T. W., Schalken, J. A., Epstein, J. I., and Isaacs, W. B. Allelic loss of chromosomes 16q and 10q in human prostate cancer. *Proc. Natl. Acad. Sci. USA*, 87: 8751–8755, 1990.
3. Sakr, W. A., Macoska, J. A., Benson, P., Grignon, D. J., Wolman, S. R., Pontes, J. E., and Crissman, J. D. Allelic loss in locally metastatic, multisampled prostate cancer. *Cancer Res.*, 54: 3273–3277, 1994.
4. Kunimi, K., Bergerheim, U. S., Larsson, I. L., Ekman, P., and Collins, V. P. Allelotyping of human prostatic adenocarcinoma. *Genomics*, 11: 530–536, 1991.
5. Cher, M. L., Bova, G. S., Moore, D. H., Small, E. J., Carroll, P. R., Pin, S. S., Epstein, J. I., Isaacs, W. B., and Jensen, R. H. Genetic alterations in untreated prostate cancer metastases and androgen-independent prostate cancer detected by comparative genomic hybridization and allelotyping. *Cancer Res.*, 56: 3091–3102, 1996.
6. Visakorpi, T., Kallioniemi, A., Syvanen, A. C., Hyytiäinen, E. R., Karhu, R., Tammela, T., Isola, J. J., and Kallioniemi, O. P. Genetic changes in primary and recurrent prostate cancer by comparative genomic hybridization. *Cancer Res.*, 55: 342–347, 1995.
7. Bova, G. S., and Isaacs, W. B. Review of allelic loss and gain in prostate cancer. *World J. Urol.*, 14: 338–346, 1996.
8. Marshall, C. T. Tumor suppressor genes. *Cell*, 64: 313–326, 1991.
9. Friend, S. H., Bernards, R., Rogelj, S., Weinberg, R. A., Rapaport, J. M., Albert, D. M., and Dryja, T. P. A human DNA segment with properties of the gene that predisposes to retinoblastoma and osteosarcoma. *Nature (Lond.)*, 323: 643–646, 1986.
10. Li, J., Yen, C., Liaw, D., Podsypanina, K., Bose, S., Wang, S. I., Puc, J., Miliareis, C., Rodgers, L., McCombie, R., Bigner, S. H., Giovanella, B. C., Ittmann, M., Tycko, B., Hibshoosh, H., Wigler, M. H., and Parsons, R. *PTEN*, a putative protein tyrosine phosphatase gene mutated in human brain, breast, and prostate cancer. *Science (Washington DC)*, 275: 1943–1947, 1997.
11. Morton, R. A., Ewing, C. M., Nagafuchi, A., Tsukita, S., and Isaacs, W. B. Reduction of E-cadherin levels, and deletion of the α -catenin gene in human prostate cancer cells. *Cancer Res.*, 53: 3585–3590, 1993.
12. Paul, R., Ewing, C. M., Jarrard, D. F., and Isaacs, W. B. The cadherin cell-cell adhesion pathway in prostate cancer progression. *Br. J. Urol.*, 79 (Suppl. 1): 37–43, 1997.
13. Suzuki, H., Freije, D., Nusskern, D. R., Okami, K., Cairns, P., Sidransky, D., Isaacs, W. B., and Bova, G. S. Interfocal heterogeneity of *PTEN/MMAC1* gene alterations in multiple metastatic prostate cancer tissues. *Cancer Res.*, 58: 204–209, 1998.
14. Bookstein, R., Bova, G. S., MacGrogan, D., Levy, A., and Isaacs, W. B. Tumour-suppressor genes in prostatic oncogenesis: a positional approach. *Br. J. Urol.*, 79 (Suppl. 1): 28–36, 1997.
15. Lisitsyn, N., Lisitsyn, N., and Wigler, M. Cloning the differences between two complex genomes. *Science (Washington DC)*, 259: 946–951, 1993.
16. Schutte, M., da Costa, L. T., Hahn, S. A., Moskaluk, C., Hoque, A. T., Rozenblum, E., Weinstein, C. L., Bittner, M., Meltzer, P. S., Trent, J. M., Yeo, C. J., Hruban, R. H., and Kern, S. E. Identification by representational difference analysis of a homozygous deletion in pancreatic carcinoma that lies within the BRCA2 region. *Proc. Natl. Acad. Sci. USA*, 92: 5950–5954, 1995.
17. McCombie, W. R., Heiner, C., Kelly, J. M., Fitzgerald, M. G., and Gocayne, J. D. Rapid and reliable fluorescent cycle sequencing of double stranded templates. *DNA Seq.*, 2: 289–296, 1992.
18. Dib, C., Faure, S., Fizames, C., Samson, D., Drouot, N., Vignal, A., Millasseau, P., Marc, S., Hazan, J., Seboun, E., Lathrop, M., Gyapay, G., Morissette, J., and Weissbach, J. A comprehensive genetic map of the human genome based on 5,264 microsatellites. *Nature (Lond.)*, 380: 152–154, 1996.
19. Berube, N. G., Spevak, M. D., and Chevrete, M. Suppression of tumorigenicity of human prostate cancer cells by introduction of human chromosome del(12)(q13). *Cancer Res.*, 54: 3077–3081, 1994.
20. Sato, T., Saito, H., Morita, R., Koi, S., Lee, J. H., and Nakamura, Y. Allelotype of human ovarian cancer. *Cancer Res.*, 51: 5118–5122, 1991.
21. Baccichet, A., and Sinnett, D. Frequent deletion of chromosome 12p12.3 in children with acute lymphoblastic leukaemia. *Br. J. Haematol.*, 99: 107–114, 1997.
22. Takeuchi, S., Mori, N., Koike, M., Slater, J., Park, S., Miller, C. W., Miyoshi, I., and Koeffler, H. P. Frequent loss of heterozygosity in region of the *KIP1* locus in non-small cell lung cancer: evidence for a new tumor suppressor gene on the short arm of chromosome 12. *Cancer Res.*, 56: 738–740, 1996.

⁵ www.ncbi.nlm.nih.gov/SCIENCE96.

Deletion Mapping at 12p12-13 in Metastatic Prostate Cancer

Adam S. Kibel,^{1*} Diha Freije,¹ William B. Isaacs,^{1,2} and G. Steven Bova^{1,2,3}

¹James Buchanan Brady Urological Institute, Johns Hopkins Medical Institutions, Baltimore, Maryland

²Department of Pathology, Johns Hopkins Medical Institutions, Baltimore, Maryland

³Department of Oncology, Johns Hopkins Medical Institutions, Baltimore, Maryland

The identification of homozygous deletions in malignant tissue is a powerful tool for the localization of tumor suppressor genes. Representational difference analysis (RDA) uses selective hybridization and the polymerase chain reaction (PCR) to isolate regions of chromosomal loss and has facilitated the identification of tumor suppressor genes, such as *BRCA2* and *PTEN*. We have recently identified a 1-5-cM homozygous deletion on 12p12-13 in a prostate cancer xenograft and found that 47% of patients who died of prostate carcinoma demonstrate focal loss of heterozygosity (LOH) in this region in metastatic deposits. We have now characterized the region of interest by assembling a yeast artificial chromosome (YAC) contig spanning the homozygous deletion and identifying which known genes and expressed sequence tags (EST) lie within the homozygous deletion. A rib metastasis was harvested at autopsy and placed subcutaneously in a male SCID mouse. Genomic DNA from this xenograft and from the patient's normal renal tissue was extracted. Multiplex PCR, with the xenograft and normal DNA used as template, was performed using primers for loci on the Whitehead contig 12.1 believed to be near our region of interest. We found that our deletion lay in a 1-2-Mb interval between WI-664 and D12S358. We then used the same primers to construct a YAC contig across the homozygous deletion. PCR amplification of YAC DNA, using primers for the genomic sequences of known genes and ESTs reported to lie on 12p12-13, was used to identify candidate genes that lay within the deletion. Duplex PCR, with control primers known not to be deleted in the xenograft, was used to confirm that both the *CDKN1B* and *ETV6* genes were homozygously deleted in the xenograft. Mutations in either or both of these genes may play an important role in metastatic prostate carcinoma. *Genes Chromosomes Cancer* 25:270-276, 1999. © 1999 Wiley-Liss, Inc.

INTRODUCTION

The deletion of genomic DNA is a common feature of neoplastic cells. Loss of these regions can inactivate tumor suppressor genes important in the initiation and progression of malignancy. Identification of homozygous deletions in malignant tissue has been strongly associated with the presence of suppressor gene loci (Marshall, 1991). *RB1* (Friend et al., 1986) and *PTEN* (Li et al., 1997) are two examples of tumor suppressor genes that were identified at least partly through the recognition of homozygous deletion of these genes in various cancerous tissues or cell lines.

We have recently identified a homozygous deletion in a prostate cancer xenograft by using representational difference analysis (RDA) (Kibel et al., 1998). The deletion was mapped to a 1-5-cM region of chromosome arm 12p bounded by the polymorphic markers D12S77 and D12S358. In addition, we determined that 9/19 (47%) of cryostat-microdissected metastatic prostate tumors obtained from different patients demonstrate focal loss of heterozygosity (LOH) in this region. The region of maximum LOH overlapped the homozygous deletion (Kibel et al., 1998).

Of the three previously described homozygous deletions in prostate cancer, two have been found to contain genes important in prostate cancer. Morton et al. (1993) described a homozygous deletion in the human prostate cancer cell line PC-3 of the α -catenin gene. This protein helps mediate cell-cell adhesion through the E-cadherin protein complex. Abnormalities in this pathway have been implicated in high-grade and high stage disease (Paul et al., 1997). The recently cloned *PTEN* gene is homozygously deleted in two prostate cancer cell lines (Li et al., 1997) and is frequently altered in advanced prostate cancer (Suzuki et al., 1998). Only the third homozygous deletion, at 8p22, described by Bova et al. (1993), has not yet been linked to a proved tumor suppressor locus (Bookstein et al., 1997).

The region on 12p12-13 has not been previously implicated in prostate cancer, but has been implicated in other malignancies, such as acute lympho-

Supported by: American Cancer Society; grant number: 58-005-39-IRG (to ASK); SPORC; grant number: CA 58236 (to WBI); CaPCURE; grant numbers: NCI CA 58236, NCI CA 59457 (to GSB).

*Correspondence to: Adam S. Kibel, Department of Urology, Johns Hopkins Hospital, 600 North Wolfe Street, Marburg 105, Baltimore, MD 21287.

Received 2 December 1998; Accepted 9 February 1999

blastic leukemia (ALL) (Baccichet and Sinnott, 1997) and ovarian (Sato et al., 1991) and non-small-cell lung cancer (Takeuchi et al., 1996). This region may contain or lie in close proximity to tumor suppressor genes important in progression and/or initiation of all of these malignancies. In the work reported here, we mapped the deletion on the Whitehead 12.1 contig and determined the location of known genes and expressed sequence tags (EST) in relation to this region of homozygous deletion.

MATERIALS AND METHODS

Xenograft and Normal DNA

The xenograft was developed from a rib metastasis from a 55-year-old man with a metastatic, androgen-deprived prostate carcinoma and confirmed to be of prostatic origin, as described previously (Kibel et al., 1998). DNA was extracted from normal tissue from the same patient and from the xenograft as described previously (Bova et al., 1993). Internal review board-approved informed consent was obtained from the patient.

Uniplex and Duplex Polymerase Chain Reaction (PCR) Amplification

Primers were designed for DNA sequences known to lie on the Whitehead contig 12.1 in the region of the homozygous deletion and were purchased from Genosys (Woodlands, TX): D12S1674, 5'-GTGATAGAGCGAGACTCCAT-3' and 5'-CCCTACTTCAAACAAGAGAGC-3'; D12S77, 5'-GAAGGGCAACAACAGTGAA-3' and 5'-CTTTT-TTTTCTCCCCCACTC-3'; WI-9218, 5'-GTTG-CTGGGATTACTGACACA-3' and 5'-TTCCAAT-CATAACGGTCTGC-3'; WI-664, 5'-CTTGGTG-GCTGTTTGGGAAAG-3' and 5'-TTAGATGA-ACTCGCCCGAAGG-3'; D12S89, 5'-ATTTGAG-AGCAGCGTGGTTTTT-3' and 5'-CCATTATG-GGGAGTAGGGGT-3'; WI-4385, 5'-AACTGCAA-CTGCCTACTATGT-3' and 5'-TGTAAGGAA-GGGAAGAACA-3'; D12S391, 5'-CTGTATTAG-TAAGGCTTCTCC-3' and 5'-AGTGTCCCT-GGGTCTC-3'; D12S358, 5'-GCCTTTGGGAA-ACTTTGG-3' and 5'-GCACAGATGAGATCCC-GT-3'; and WI-2685, 5'-CAGAGGCTGCAAAGCA-CATCT-3' and 5'-CGCACATATGACACCAGG-GAG-3'.

PCR amplification with these primers was used to create a map of the homozygous deletion on the Whitehead contig 12.1. Six microliters of forward primer (20 μ M) was end-labeled with 3- μ l γ -³²P adenosine triphosphate (ICN, Irvine, CA) using 20 units of T4 kinase (Life Technologies, Rockville, MD). The reaction mixture was incubated at 37°C

for 1 hr, followed by T4 kinase inactivation by incubation at 68°C for 20 min.

Thirty to fifty nanograms of genomic tumor or noncancerous DNA underwent PCR amplification with 80 nmoles of labeled forward primer and unlabeled reverse primer. Amplified PCR fragments were denatured at 94°C for 5 min and cooled on ice. Two microliters of each sample was separated by polyacrylamide urea gel electrophoresis and autoradiographed. In cases where the noncancerous DNA reaction produced product but the tumor sample did not, the reactions using both tumor and noncancerous DNA were repeated under identical conditions with the original primers and with the addition of a second set of γ -³²P-labeled primers (D13S328, purchased from Research Genetics, Huntsville, AL) known to be rarely homozygously deleted (data not shown) to serve as an internal reaction control. Amplification of the control fragment, but not the fragment of interest in the tumor sample, coupled with normal amplification of both fragments in the noncancerous DNA sample indicated the presence of a homozygous deletion.

Yeast Artificial Chromosomes (YAC) Contig

YACs reported to lie in the region on the homozygous deletion were obtained from Research Genetics and grown on YPD plates at 30°C for 2 days. DNA from individual colonies was used as template in PCR reactions using 3.6 pmoles of primer for D12S1674, D12S77, WI-9128, WI-664, D12S89, WI-4385, D12S391, D12S358, and WI-2685. Individual clones whose DNA was amplified by contiguous genomic markers in the region of the homozygous deletion were selected for further analysis.

Gene/EST Localization

Primers were designed for genomic sequences of genes and ESTs that were reported to lie in the region of the homozygous deletion (www.ncbi.nlm.nih.gov/science96) and purchased from Genosys. Primers for each gene or EST are listed in Table 1. Five nanograms of each YAC-purified DNA underwent PCR amplification with 3.6 pmoles of each primer. Amplified PCR fragments were separated on 7% polyacrylamide gels, stained with ethidium bromide, and photographed.

All genomic sequences that were found to lie in the region of the homozygous deletion underwent PCR using xenograft and normal DNA as template and radiolabeled primers, as described above. Again to confirm homozygous deletions, reactions were repeated under identical conditions with the addi-

TABLE 1. Location of Genes and ESTs Examined on the YAC Contig^a

Genomic locus	Gene at locus	Location (Fig. 1C)	Deleted in xenograft	Primers (5' to 3')
D12S1936	Microsomal glutathione S-transferase	Off contig	Not tested	AGCAGAGGAATTATGAACTGGCAAAAG-TGAGGTGTGTGTGA
SGC 34934	EST	Off contig	Not tested	GAACAATTGGGAAGCAAATGTTAATC-CAAAGAGGTGGACAG
SGC 34321	EST	Off contig	Not tested	CACCTCCCCCAAAACATATATTCTTC-CACACCGTCCAG
D12S1909	EST	Off contig	Not tested	AAAGGTTTCAGGATGTTTATTGATGCC-TGTTTTCTGTATCTT
StSG317	Cation-dependent mannose-6-phosphate receptor precursor	Off contig	Not tested	GGACACAAAAGAGGGATGGGGGAGG-GATGCAAAACAAAT
SHCG 12935	Human epidermal growth factor receptor kinase substrate	Off contig	Not tested	TAATTATTTTATCCCCATCCCAGCTA-TGCCCTGAATGA
D12S1900	Placental growth factor	Off contig	Not tested	CTGCTGGTACCTGCCCTCTATTAGCTT-GCCCTCAGAG
A006O20	EST	1	Not tested	GCACTGTGTACTGAAAACCTGTCTTT-TTGCTGTGTGGTAAG
L19161	Translational initiation factor 2 gamma subunit	2	Not tested	TTCTGCTTAGACGGCTTCTACGCCA-GTGTTTTTCAACTCT
A006W05	EST	2	Not tested	TGATTATCGTCCCAACTTTGTGGATGA-CCCCAAGAAGGAT
WI-11901	EST	2	Not deleted	TTTTACCGCAATCAACAAGTACGGGAA-ATAATAACACCTCAG
SGC 35438	NKG2-C type II integral membrane protein	2	Not deleted	TTGCATGTTATGTGAGTCAGCATTCCG-AAAGTTACAACCATC
D12S1916	EST	2	Not tested	CACCCACAAAATCCCAAGCCATGC-TGCTGTCCCTTCA
SGC 35334	Human acidic proline rich protein gene	2	Not tested	AGCCCTTACATAACCAACAGCGGAGAT-GCAAGCCCCCTAC
WI-9218	Human lectin-like type II integral membrane protein	2	Not deleted	GTTGCTATTACTGACACATTCCAAT-CATAACGGTCTGC
WI-7055	NKG2-A type II integral membrane protein	2	Not tested	GCTCAACATGGTATTTGTGTAGAAAGT-TTTCATCACGACA
A008B32	ETV6	3	Deleted	TTTTTGAACAAGGAGCCCTACGAGTTA-GTGTTCCGGCAGGACT
StSG4303	ETV6	3	Deleted	TGGTGGCGGTACAAAAGAGCTGCAGAC-CCCCTGAA
D12S1898	ETV6	3	Deleted	CAGGATTGCTGGAAGTGTGACGCCTGT-GCTGGGTAGTTTGTC
A009A32	EST	4	Not deleted	CCGTCTTTCCAAGTCTATGGAAGAGC-AGTACAGGCAGAAG
A005C29	EST	4	Not deleted	GAACATAACATTTACAGGGACCCAGCG-CATTACCACTCATC
p27 3' exon I	CDKN1B	4	Deleted	GGCTCCGGCTAACTCTGAGGGTCTGA-AGGCCCAACACAT

^aNumbers in location column correspond to Figure 1C. PCR was initially run against the YAC contig. If the locus was located in a region possibly homozygously deleted (region 3 and 4), PCR was repeated using xenograft as template. All PCRs demonstrating evidence of homozygous deletion were repeated in a multiplex reaction using D13S328 or D8S549 as a positive control. The ETV6 gene and CDKN1B were found to lie within the homozygous deletion.

tion of γ -³²P-labeled primers (D13S328 purchased from Research Genetics). Amplification of this second set of markers served as an additional control for variations in DNA template concentration.

RESULTS

PCR amplification of genomic sequences located in the region of our previously described deletion

(Kibel et al, 1998) on the Whitehead contig 12.1 demonstrated that D12S89, WI-4385, and D12S391 were homozygously deleted in the xenograft, whereas flanking markers D12S77, WI-9128, WI-664, and D12S358 were not (Fig. 1B and D). Reactions were repeated using multiplex PCR to provide a positive control in each PCR reaction. This established the boundaries of the deletion at WI-664 and D12S358.

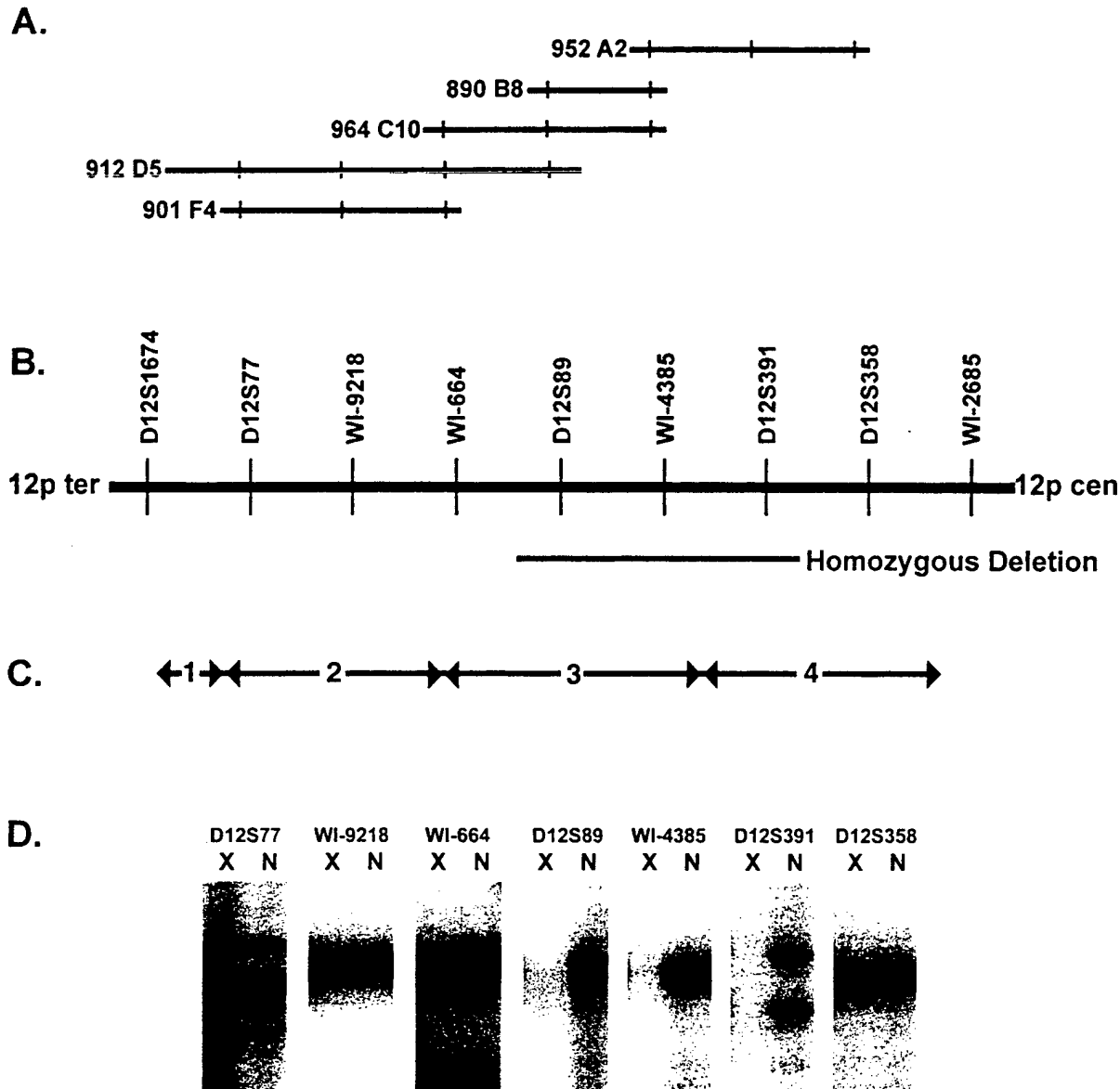


Figure 1. Map of homozygous deletion by PCR analysis. **A:** YAC contig across the deletion at 12p12-13. **B:** Line drawing of the deleted region on a Whitehead 12.1 contig. **C:** Location of genes and ESTs on the YAC contig (see Table 1). **D:** Markers D12S89, WI-4385, and

D12S391 are homozygously deleted, while D12S77, WI-9218, WI-664, and D12S358 are not. To confirm the deletion, markers were rerun multiplexed with D13S328 or D8S549 (data not shown).

The YAC contig constructed around this deletion (Fig. 1A) demonstrates that the entire deletion lies within YACs 952 A2 and 964 C10. PCR amplification of genes and ESTs reported to lie in this region (Table 1) demonstrated that only a minority were located in the region of the deletion (Fig. 1C, regions 3 and 4). The xenograft and normal DNA underwent PCR amplification for all genes and ESTs mapped to YACs 952 A2 and 964 C10, and for several that were believed not to lie within the deletion. Only the *CDKN1B* and *ETV6* genes were found to be homozygously deleted (Fig. 2).

DISCUSSION

An approach to identifying candidate tumor suppressor genes is to identify homozygous deletions of genomic DNA within tumors. RDA has been useful in facilitating identification of these regions. The *PTEN* gene was isolated by performing RDA on human breast cancer cells. A homozygously deleted region was identified at 10q23. Subsequent analysis showed that this deletion contained the *PTEN* gene and that it was frequently deleted in breast, brain, and prostate cancer (Li et al., 1997). A

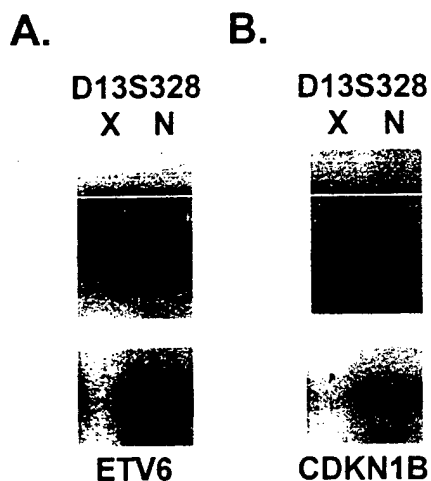


Figure 2. Multiplex PCR of noncancerous (N) and xenograft (X) template using primers designed from (A) *ETV6* and (B) *CDKN1B* genes and using D13S328 as a control. Lanes containing xenograft template demonstrate normal amplification of D13S328 and no amplification of either *CDKN1B* or *ETV6*.

similar experimental design was used by Schutte et al. (1995), in which analysis of a pancreatic cancer xenograft demonstrated a homozygous deletion at 13q12.3 in the region of *BRCA2*.

We have recently used RDA to identify a possible prostate cancer tumor suppressor locus at 12p12–13 (Kibel et al., 1998). The homozygous deletion was identified by RDA and confirmed by Southern analysis and multiplex PCR. Using the National Center for Biotechnology Information database, and polymorphic primers located in the area of the deletion, we mapped the deletion to a 1–5-cM region of 12p. In addition, we demonstrated that the homozygous deletion also existed in a metastasis from the same patient, indicating that the deletion was not simply an artifact of the xenografting process, and that 47% of patients demonstrated LOH at 12p12–13 in their metastatic deposits, indicating that genetic abnormalities at this site are common in prostate cancer (Kibel et al., 1998).

Our current study further narrows the homozygously deleted region to a 1–2-Mb region of 12p12–13. Because WI-664 has not been mapped on a genomic or radiation hybrid map, a more exact size determination is not possible at this time. However, the entire deletion lies within the two overlapping YACs 952 A2 and 964 C10 (Fig. 1A). In addition, we examined 11 known genes and 9 ESTs and found that only 2 were located within the homozygous deletion: the *CDKN1B* and *ETV6* genes (Table 1). Multiplex PCR was used with a nondeleted locus (D13S328) to serve as an internal positive control of PCR conditions and as an indicator of starting

template quality and integrity (Fig. 2). Genes and ESTs were mapped initially on a YAC contig to demonstrate their close proximity to the region of interest.

CDKN1B, also known as p27 or KIP1, is a negative regulator of the cell cycle and functions by binding to G1-specific cyclin-cdk complexes such as cyclin E-cdk2, cyclin A-cdk2, and cyclin D2-cdk4 (Polyak et al., 1994; Toyoshima et al., 1994). Abnormalities in *CDKN1B* have been found in a variety of malignancies, including breast (Catzavelos et al., 1997), colon (Loda et al., 1997), lung (Yatabe et al., 1998), and prostate (Guo et al., 1997; Cheville et al., 1998; Cordon-Cardo et al., 1998; Cote et al., 1998; Tsihlias et al., 1998; Yang et al., 1998) carcinomas.

Six recently published studies have presented strong evidence that *CDKN1B* plays an important role in prostate cancer. Guo et al. (1997) examined 40 primary prostate tumors and 5 lymph node metastases, using immunohistochemistry, and found that decreased staining correlated with a high proliferative index (as measured by Ki-67 staining) and tumor grade. Importantly, fully 67.5% of the primary tumors and 40% of the metastatic foci were completely negative for *CDKN1B*. Yang et al. (1998) examined 86 radical prostatectomy specimens from patients with clinically organ-confined disease for *CDKN1B* expression, again by immunohistochemistry. They found that absent or low expression by immunohistochemistry was a strong independent risk factor for disease-free survival by multivariate analysis. In similar studies, Tsihlias et al. (1998) and Cordon-Cardo et al. (1998) report that decreased *CDKN1B* staining was a strong independent risk factor for treatment failure. In contrast, Cheville et al. (1998) examined 138 radical prostatectomy specimens and found that although decreased *CDKN1B* staining correlated with a higher Gleason score and pathologic stage, it did not correlate with biochemical failure. Lastly, Cote et al. (1998) used immunohistochemistry to determine the nuclear levels of *CDKN1B* in 96 pathologic stage C primary prostate tumors. They found that decreased *CDKN1B* levels were correlated not only with decreased disease-free survival but also with overall survival in this patient population. Interestingly, whereas immunohistochemistry has demonstrated decreased *CDKN1B* expression in prostate carcinoma, no prior study to date has shown deletions, mutations, or other genetic alterations in this gene in prostate cancer (Kawamata et al., 1995; Ponce-Castaneda et al., 1995). However, both groups examined only localized disease. To our knowledge, there are no previous studies other

than the one reported here, that examined *CDKN1B* in metastatic deposits.

ETV6, also known as TEL, is a member of the ETS family of transcription factors, but its exact function is unknown. It was initially identified as a protein fused to platelet-derived growth factor receptor β (Golub et al., 1994). The formation of chimeric *ETV6* fusion transcripts appears to be important in several hematologic malignancies (Golub et al., 1995; Papadopoulos et al., 1995; Carroll et al., 1996; Golub, 1997) and the *ETV6* gene has been implicated as possible tumor suppressor gene in ALL because LOH has frequently been identified at this site (Baccichet and Sinnett, 1997). Whereas *ETV6* is expressed in a wide variety of tissues (Golub et al., 1994), the only other malignancy in which *ETV6* has been implicated is congenital fibrosarcoma through fusion of *ETV6* to the *NTRK3*, neurotrophin-3 receptor, gene. (Knezevich et al., 1998). To our knowledge, *ETV6* has not previously been implicated in prostate cancer.

Either of these genes is a strong candidate tumor suppressor gene at this locus, but it should be recognized that other genes may lie within this 1-2-Mb homozygous deletion. It is possible that one of these unknown genes is the responsible prostate tumor suppressor. An alternative hypothesis is that no tumor suppressor lies at this site. Although the fact that 47% of metastatic foci from different patients demonstrated LOH at 12p12-13 provides strong supportive evidence of a tumor suppressor gene at this site, we note that another site of a homozygous deletion (8p22) also frequently demonstrates LOH, and no prostatic tumor suppressor gene has been identified at that site to date (Bookstein et al., 1997).

In conclusion, we have identified a novel homozygous deletion in a metastatic prostate cancer xenograft. We have created a YAC contig across this deletion, determined the loci of 20 genes and ESTs, and narrowed the region of interest to a 1-2-Mb region of 12p12-13. The deletion includes both the *CDKN1B* and *ETV6* genes, each of which has previously been implicated in malignancy. Immunohistochemical abnormalities of *CDKN1B* have previously been linked to prostate carcinoma, but this is the first report of a mutation in this gene in this disease. This report is also the first suggesting that *ETV6* inactivation may play a role in metastatic prostate cancer. It is possible that neither of these genes is important in metastatic prostate carcinoma and an as yet unidentified tumor suppressor gene(s) that lies in close proximity to these two genes is truly responsible for the progression and/or initiation of metastasis.

ACKNOWLEDGMENTS

We thank Mario Eisenberger, Michael Carducci, Pendleton Powers, and Vickie Sinibaldi for clinical assistance, and John T. Isaacs, John Lamb, Charles M. Ewing, Dennis Faith, and Debra Nusskern for technical assistance. A.S.K. is an American Foundation of Urologic Disease Scholar.

REFERENCES

- Baccichet A, Sinnett D. 1997. Frequent deletion of chromosome 12p12.3 in children with acute lymphoblastic leukaemia. *Br J Haematol* 99:107-114.
- Bookstein R, Bova GS, MacGrogan D, Levy A, Isaacs WB. 1997. Tumour-suppressor genes in prostatic oncogenesis: a positional approach. *Brit J Urol* 79(suppl 1):28-36.
- Bova GS, Carter BS, Bussemakers MJ, Emi M, Fujiwara Y, Kyprianou N, Jacobs SC, Robinson JC, Epstein JI, Walsh PC, Isaacs WB. 1993. Homozygous deletion and frequent allelic loss of chromosome 8p22 loci in human prostate cancer. *Cancer Res* 53:3869-3873.
- Carroll M, Tomasson MH, Barker GF, Golub TR, Gilliland DG. 1996. The TEL/platelet-derived growth factor beta receptor (PDGF beta R) fusion in chronic myelomonocytic leukemia is a transforming protein that self-associates and activates PDGF beta R kinase-dependent signaling pathways. *Proc Nat Acad Sci USA* 93:14845-14850.
- Catzavelos C, Bhattacharya N, Ung YC, Wilson JA, Roncari L, Sandhu C, Shaw P, Yeager H, Morava-Protzner I, Kapusta L, Franssen E, Pritchard KI, Slingerland JM. 1997. Decreased levels of the cell-cycle inhibitor p27Kip1 protein: prognostic implications in primary breast cancer. *Nat Med* 3:227-230.
- Chevillat JC, Lloyd RV, Sebo TJ, Cheng L, Erickson L, Bostwick DG, Lohse CM, Wollan P. 1998. Expression of p27kip1 in prostatic adenocarcinoma. *Mod Pathol* 11:324-328.
- Cordon-Cardo C, Koff A, Drobnjak M, Capodiceci P, Osman I, Millard SS, Gaudin PB, Fazzari M, Zhang ZF, Massague J, Scher HI. 1998. Distinct patterns of p27/kip1 gene expression in benign prostatic hyperplasia and prostatic carcinoma. *J Nat Cancer Inst* 90:1284-1291.
- Cote RJ, Shi Y, Groshen S, Feng AC, Cordon-Cardo C, Skinner D, Liebkovosky G. 1998. Association of p27Kip1 levels with recurrence and survival in patients with stage C prostate carcinoma. *J Nat Cancer Inst* 90:916-920.
- Friend SH, Bernards R, Rogelj S, Weinberg RA, Rapaport JM, Albert DM, Dryja TP. 1986. A human DNA segment with properties of the gene that predisposes to retinoblastoma and osteosarcoma. *Nature* 323:643-646.
- Golub TR, Barker GF, Lovett M, Gilliland DG. 1994. Fusion of PDGF receptor beta to a novel ets-like gene, tel, in chronic myelomonocytic leukemia with t(5;12) chromosomal translocation. *Cell* 77:307-316.
- Golub TR, Barker GF, Bohlander SK, Hiebert SW, Ward DC, Bray-Ward P, Morgan E, Raimondi SC, Rowley JD, Gilliland DG. 1995. Fusion of the TEL gene on 12p13 to the AML1 gene on 21q22 in acute lymphoblastic leukemia. *Proc Nat Acad Sci USA* 92:4917-4921.
- Golub TR. 1997. TEL gene rearrangements in myeloid malignancy. *Hematol Oncol Clin North Am* 11:1207-1220.
- Guo Y, Sklar GN, Borkowski A, Kyprianou N. 1997. Loss of the cyclin-dependent kinase inhibitor p27Kip1 protein in human prostate cancer correlates with tumor grade. *Clin Cancer Res* 3:2269-2274.
- Kawamata N, Morosetti R, Miller CW, Park D, Spirin KS, Nakamaki T, Takeuchi S, Hatta Y, Simpson J, Wilczynski S, Lee YY, Bartram CR, Koeffler HP. 1995. Molecular analysis of the cyclin-dependent kinase inhibitor gene p27/kip1 in human malignancies. *Cancer Res* 55:2266-2269.
- Kibel AS, Schutte M, Kern SE, Isaacs WB, Bova GS. 1998. Identification of 12p as a region of frequent deletion in advanced prostate cancer. *Cancer Res* 58:5652-5655.
- Knezevich SR, McFadden DE, Tao W, Lim JF, Sorensen PH. 1998. A novel *ETV6-NTRK3* gene fusion in congenital fibrosarcoma. *Nat Genet* 18:184-187.
- Li J, Yen C, Liaw D, Podsypanina K, Bose S, Wang SI, Puc J, Milaresis C, Rodgers L, McCombie R, Bigner SH, Giovannella BC, Ittmann M, Tycko B, Hibshoosh H, Wigler MH, Parsons R. 1997.

- PTEN, a putative protein tyrosine phosphatase gene mutated in human brain, breast, and prostate cancer. *Science* 275:1943-1947.
- Loda M, Cukor B, Tam SW, Lavin P, Fiorentino M, Draetta GF, Jessup JM, Pagano M. 1997. Increased proteasome-dependent degradation of the cyclin-dependent kinase inhibitor p27 in aggressive colorectal carcinomas. *Nat Med* 3:231-234.
- Marshall CT. 1991. Tumor suppressor genes. *Cell* 64:313-326.
- Morton RA, Ewing CM, Nagafuchi A, Tsukita S, Isaacs WB. 1993. Reduction of E-cadherin levels, and deletion of the alpha-catenin gene in human prostate cancer cells. *Cancer Res* 53:3585-3590.
- Papadopoulos P, Ridge SA, Boucher CA, Stocking C, Wiedemann LM. 1995. The novel activation of ABL by fusion to an ets-related gene, TEL. *Cancer Res* 55:34-38.
- Paul R, Ewing CM, Jarrard DF, Isaacs WB. 1997. The cadherin cell-cell adhesion pathway in prostate cancer progression. *Brit J Urol* 79(suppl 1):37-43.
- Polyak K, Lee MH, Erdjument-Bromage H, Koff A, Roberts JM, Tempst P, Massague J. 1994. Cloning of p27Kip1, a cyclin-dependent kinase inhibitor and a potential mediator of extracellular antimitogenic signals. *Cell* 78:59-66.
- Ponce-Castaneda MV, Lee MH, Latres E, Polyak K, Lacombe L, Montgomery K, Mathew S, Krauter K, Sheinfeld J, Massague J, Cordon-Cardo C. 1995. p27Kip1: chromosomal mapping to 12p12-12p13.1 and absence of mutations in human tumors. *Cancer Res* 55:1211-1214.
- Sato T, Saito H, Morita R, Koi S, Lee JH, Nakamura Y. 1991. Allelotype of human ovarian cancer. *Cancer Res* 51:5118-5122.
- Schutte M, da Costa LT, Hahn SA, Moskaluk C, Hoque AT, Rozenblum E, Weinstein CL, Bittner M, Meltzer PS, Trent JM, Yeo CJ, Hruban RH, Kern SE. 1995. Identification by representational difference analysis of a homozygous deletion in pancreatic carcinoma that lies within the BRCA2 region. *Proc Nat Acad Sci USA* 92:5950-5954.
- Suzuki H, Freije D, Nusskern DR, Okami K, Cairns P, Sidransky D, Isaacs WB, Bova GS. 1998. Interfocal heterogeneity of PTEN/MMAC1 gene alterations in multiple metastatic prostate cancer tissues. *Cancer Res* 58:204-209.
- Takeuchi S, Mori N, Koike M, Slater J, Park S, Miller CW, Miyoshi I, Koeffler HP. 1996. Frequent loss of heterozygosity in region of the KIP1 locus in non-small cell lung cancer: evidence for a new tumor suppressor gene on the short arm of chromosome 12. *Cancer Res* 56:738-740.
- Toyoshima H, Hunter T. 1994. p27, a novel inhibitor of G1 cyclin-cdk protein kinase activity, is related to p21. *Cell* 78:67-74.
- Tsihlias J, Kapusta LR, DeBoer G, Morava-Prutzner I, Zbieranowski I, Bhattacharya N, Catzavelos GC, Klotz LH, Slingerland JM. 1998. Loss of cyclin-dependent kinase inhibitor p27Kip1 is a novel prognostic factor in localized human prostate adenocarcinoma. *Cancer Res* 58:542-548.
- Yang RM, Naitoh J, Murphy M, Wang HJ, Phillipson J, deKernion JB, Loda M, Reiter RE. 1998. Low p27 expression predicts poor disease-free survival in patients with prostate cancer. *J Urol* 159:941-945.
- Yatabe Y, Masuda A, Koshikawa T, Nakamura S, Kuroishi T, Osada H, Takahashi T, Mitsudomi T, Takahashi T. 1998. p27KIP1 in human lung cancers: differential changes in small cell and non-small cell carcinomas. *Cancer Res* 58:1042-1047.

LOSS OF HETEROZYGOSITY AT 12P12-13 IN PRIMARY AND METASTATIC PROSTATE ADENOCARCINOMA

ADAM S. KIBEL,* DENNIS A. FAITH, G. STEVEN BOVA AND WILLIAM B. ISAACS

From the Departments of Urology, Pathology and Oncology, Johns Hopkins Medical Institutions, Baltimore, Maryland

ABSTRACT

Purpose: Our laboratory has recently identified a 1 to 2 Mb homozygous deletion at 12p12-13 in a prostate cancer specimen and determined that the p27/kip1 gene lies within the deletion. While immunohistochemical analysis has implicated p27/kip1 in prostate carcinoma, no previous studies had identified genetic abnormalities at this locus. Here, we examined primary and metastatic prostate tumors to determine if allelic loss occurs at this locus in localized disease and if it increases the risk of metastatic, high stage or high-grade disease.

Materials and Methods: DNA was extracted from prostate tumors and normal tissue of 99 patients. 60 tumors were primary, 20 were metastatic pelvic lymph nodes, and 19 were distant metastases. Multiple metastases were analyzed from 11 of 19 patients with metastatic disease. Polymorphic markers spanning our region of interest were PCR amplified from tumor and normal DNA. PCR products were then scored for allelic loss.

Results: Loss of heterozygosity (LOH) was identified in 14/60 (23%) primary tumors, 6/20 (30%) lymph node metastasis, and 9/19 (47%) distant metastases. The difference between primary and distant metastatic disease was statistically significant ($p = 0.045$, Fisher's exact test). The pattern of LOH was identical in all metastatic sites obtained from individual patients, indicating that genetic loss occurred prior to metastasis. Subset analysis of the 60 primary tumors demonstrated no association between LOH and adverse pathological feature [nodal involvement, seminal vesicle invasion, margin positivity, high Gleason score (7-10)].

Conclusions: Demonstrating that 12p12-13 LOH is a prominent feature of primary prostate tumors and that multiple metastatic foci have an identical LOH pattern, provides evidence that gene inactivation in this region occurs prior to metastasis. In addition, the strong association between LOH and distant metastasis raises the possibility that mutational inactivation of a gene at 12p12-13, possibly p27/kip1, plays a pivotal role in the development of metastatic disease.

KEY WORDS: prostatic neoplasms, p27, kip1, polymorphism (genetics), loss of heterozygosity, DNA, neoplasm/analysis

Deletion of genomic DNA is a common feature of neoplasia. Genomic loss is thought to inactivate tumor suppressor genes important in the initiation and progression of malignancy. Deletions of at least one copy of 6q, 8p, 8q, 10p, 10q, 13q, 16q, 17p, 18q, 19p have been identified in prostate cancer¹⁻⁶ and presumably these regions contain tumor suppressor genes important in the initiation or progression of this malignancy.

We have recently used representational difference analysis to identify a novel homozygous deletion on 12p12-13 in a metastatic prostate cancer xenograft.^{7,8} Approximately 50% of metastatic prostate tumors demonstrate focal loss of heterozygosity (LOH) at this locus and the region of maximum LOH overlapped the homozygous deletion.⁷ This deletion contains p27/kip1,⁸ an important cell cycle regulator, which has recently been implicated in prostate carcinoma,⁹⁻¹⁴ as well as ETV6/tel,⁸ a novel transcription factor of unknown function, which has never been previously implicated in prostate carcinoma.

No previous reports have examined primary prostate tumors for LOH at 12p12-13. To determine if allelic loss occurs at this locus in localized disease and if allelic loss increases the risk of metastatic, high stage or high-grade disease, we

examined primary and metastatic prostate tumors for allelic loss in this region.

MATERIALS AND METHODS

DNA samples. Primary prostate cancer tissue and pelvic lymph node metastasis were obtained from 80 patients undergoing radical prostatectomy for clinically localized prostate carcinoma from August 1988 and December 1995. Distant metastatic foci were obtained from 18 patients with metastatic prostate cancer undergoing autopsy between January 1995 and June 1997 and one patient who underwent resection of a sacral prostate carcinoma metastasis in July 1993. Eleven of the 19 patients with distant metastasis had multiple metastatic foci obtained. DNA was extracted from normal and malignant tissue samples immediately following surgery or death as described previously.² IRB approved informed consent was obtained from patients and/or family for tissue harvest and analysis.

Multiplex PCR amplification. The genomic map available from Genethon was used to determine which polymorphic markers lay in our region of interest. Commercially available primers flanking these markers (D12S77, D12S89, D12S1697, D12S98, and D12S358) were purchased from Research Genetics (Huntsville, AL). Primers to amplify D12S391 were not commercially available, so primers were designed (5'-CTGTATTAGTAAGGCTTCTCC3' & 5'-AGTGTCCCTGGGTCTC3') and purchased from Genosys (Woodlands, TX).

PCR amplification using these primers was used to analyze

Accepted for publication January 7, 2000.

* Requests for reprints: Division of Urology, Washington University School of Medicine, 2nd Floor, Wohl Hospital, Box 8242, 4960 Children's Place, St. Louis, MO 63110.

Supported by the American Foundation of Urologic Disease, American Cancer Society Grant 58-005-39-IRG, CaPCURE, NCI Grant CA 58236, USAMRMC, and SPORE Grant CA 58236.

the tumor/normal pairs for LOH at each locus. Six μL of forward primer (20 μM) was end-labeled with 3 μL [$\gamma\text{-}^{32}\text{P}$] adenosine triphosphate (ICN, Irvine CA) using 20 units T4 kinase (Life Technologies). The reaction mixture was incubated at 37°C for one hour and the enzyme was inactivated by incubation at 68°C for 20 minutes.

Thirty to 40 ng of genomic DNA underwent PCR amplification with 15 mM dNTP and 80 nM of labeled forward primer and unlabeled reverse primer. Amplified PCR fragments were denatured at 94°C for 5 minutes, and cooled on ice. Two μL of each sample was separated by polyacrylamide urea gel electrophoresis and autoradiographed. Allelic imbalances were scored as allelic losses if by visual estimation a 50% or greater signal reduction was seen for a tumor allele as compared with the normalized retained non-cancerous allele.

Data analysis. Data were analyzed using Stata 5.0 (College Station, TX). Fisher's exact test was used to determine if 12p12-13 LOH was more strongly associated with localized or metastatic disease. In addition, the 60 primary tumors were analyzed separately to determine if an association existed between LOH and adverse pathological features, such as nodal involvement, seminal vesicle invasion, margin positivity, or high Gleason score (7-10). Comparison of age of patients with and without LOH was calculated using an unpaired *t* test with equal variance. Odds ratios (OR) with 95% confidence intervals were determined.

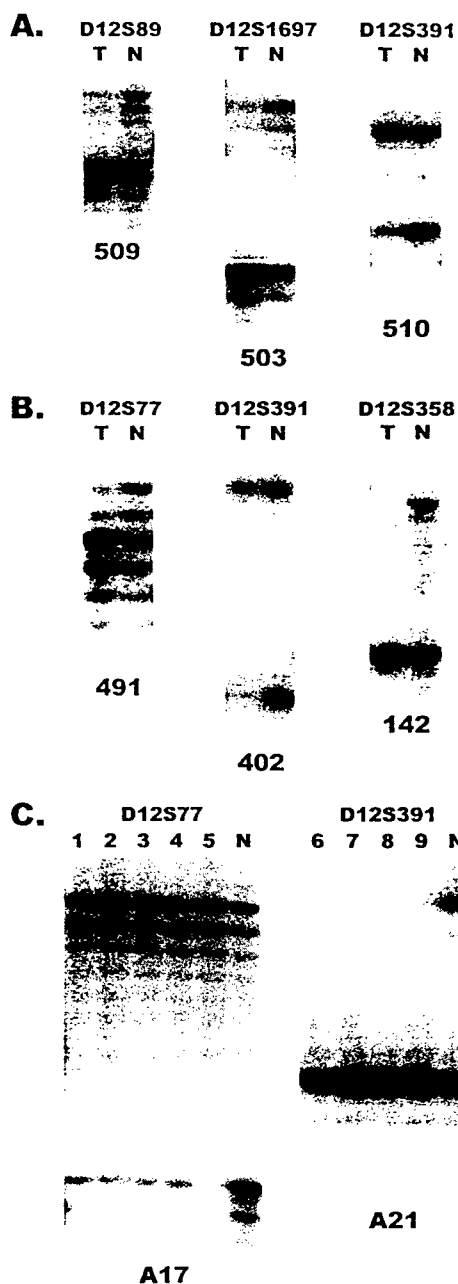
RESULTS

Loss of heterozygosity, assessed using polymorphic markers which spanned a 4.4 cM region of 12p12-13, was identified in 14/60 (23%) primary tumors (fig., A), 6/20 (30%) lymph node metastases (fig., B), and 9/19 (47%) distant metastases (fig., C) (table 1). The difference in percentage of tumors demonstrating LOH between primary and distant metastatic disease was statistically significant ($p = 0.045$, Fisher's exact test) with an odds ratio of 3.0 (CI, 1.0 to 8.6). These findings indicate that while genetic loss at this locus occurs in localized disease, it is more strongly associated with metastatic disease.

The 60 primary tumors were analyzed separately to determine if an association existed between LOH and adverse pathological features, such as nodal involvement, seminal vesicle invasion, margin positivity, or high Gleason score (7-10). The data are summarized in table 2. Only nodal involvement and high Gleason score (7-10) demonstrated a positive correlation and neither reached statistical significance. The average age at surgery was similar in the two groups; 59.7 ± 6.4 (standard deviation) in patients without LOH and 61.0 ± 7.4 (standard deviation) in patients with LOH ($p = 0.54$, unpaired *t* test). PSA levels prior to surgery were not analyzed because the majority of patients were operated on prior to the widespread availability of this test.

Microsatellite analysis of individual metastasis from the 19 autopsy patients has already been described.⁷ This study used additional markers to refine the region of interest and analyzed multiple metastases from individual patients to determine the clonality of the metastases. Additional markers did not further refine the region of interest. However, of the eleven patients with multiple metastases available for analysis, seven demonstrated LOH and the pattern was identical in all metastases examined from each individual patient (fig., C). The high percentage of primary tumors demonstrating LOH at this locus and the identical pattern of loss at different metastatic loci suggests that the different metastases are monoclonal in origin, that is they are derived from a common progenitor cell. While this progenitor cell could have been within a metastatic deposit, the simplest explanation is that it was within the primary tumor.

The smallest common region of deletion encompasses the



Examples of microsatellite analysis at 12p12-13. A, localized tumors. B, lymph node metastasis. C, distant metastasis. T = tumor template DNA, N = non-cancerous template DNA, 1 = axillary lymph node metastasis, 2 = paraaortic lymph node metastasis, 3 = supraclavicular lymph node metastasis, 4 = subdural metastasis, 5 = humeral marrow metastasis, 6 = liver metastasis #1, 7 = liver metastasis #2, 8 = adrenal metastasis, 9 = rib metastasis.

region between D12S391 and D12S358 (table 1). Only patient 748 demonstrated loss at 12p12-13 and retained both of these markers. Of particular note is patient 402 (fig., B) who demonstrates LOH at marker D12S391 but is retained at both adjacent markers. These mapping data implicate the region between D12S391 and D12S358, which contains p27/kip1.

DISCUSSION

Our previous finding of a homozygous deletion of 1 to 2 Mb in size at 12p12-13 in a prostate cancer xenograft derived from a rib metastasis provided strong evidence that a tumor suppressor gene important in prostate carcinoma existed at that site.⁸ This study expands on our previous work by dem-

LOSS OF HETEROZYGOSITY IN PROSTATE ADENOCARCINOMA

TABLE 1. High resolution deletion mapping of chromosome 12p12-13 in 29 cases demonstrating LOH

Primary Tumors						
Patient	Locus					
	D12S77	D12S89	D12S1697	D12S98	D12S391	D12S358
29	L	L	N	N	L	L
35	N	R	N	N	L	L
144	L	N	N	L	L	L
179	L	N	L	N	L	N
217	R	N	L	N	L	N
237	R	R	N	N	L	L
352	L	L	L	L	L	N
403	N	L	L	L	L	N
485	R	L	L	—	L	N
503	N	L	L	L	N	L
505	R	L	L	L	N	N
509	R	L	L	L	L	L
510	L	L	L	L	L	L
748	L	R	R	N	R	R
Lymph Node Metastasis						
Patient	Locus					
	D12S77	D12S89	D12S1697	D12S98	D12S391	D12S358
50	N	R	R	R	L	L
142	L	L	L	L	N	L
402	R	N	R	R	L	R
419	N	L	N	L	L	L
491	L	L	N	L	L	L
684	R	N	L	N	L	L
Distant Metastasis						
Patient	Locus					
	D12S77	D12S89	D12S1697	D12S98	D12S391	D12S358
A2	L	*	*	*	*	N
A3	L	L	L	L	L	N
A8	R	R	R	N	R	L
A13	L	L	L	L	L	N
A17	L	N	L	L	L	L
A18	N	L	L	L	L	L
A21	L	L	L	N	L	N
A22	L	L	L	L	L	L
391	R	N	L	L	L	N

L = LOH, N = non-informative, R = retained, — = not performed, and * = homozygous deletion.

TABLE 2. Subset analysis of 60 primary tumors

	Patients with Allelic Loss (%) n = 14	Patients without Allelic Loss (%) N = 46	OR, Allelic Loss vs. No Allelic Loss
Nodal Involvement			
Yes	3/11 (27%)	8/11 (73%)	1.30, p = 0.50
No	11/49 (22%)	38/49 (78%)	(95% CI, 0.3-5.4)
Positive Margins			
Yes	5/23 (22%)	18/23 (78%)	0.86, p = 0.54
No	9/37 (24%)	28/37 (76%)	(95% CI, 0.3-2.9)
Seminal Vesicle Invasion			
Yes	2/11 (18%)	9/11 (82%)	0.69, p = 0.50
No	12/49 (24%)	37/49 (76%)	(95% CI, 0.0-3.3)
Grade			
Gleason 5 & 6	3/11 (27%)	8/11 (73%)	1.30, p = 0.50
Gleason 7-10	11/49 (22%)	38/49 (78%)	(95% CI, 0.3-5.4)

No association existed between LOH and nodal involvement, seminal vesicle invasion, margin positivity, or high Gleason score (7-10). p values are for two-tailed Fisher's exact test.

onstrating that deletions in the region occur in localized as well as metastatic disease and that there is a statistically significant increase in LOH with metastatic disease. The fact that LOH at this locus does occur in localized disease provides evidence that gene inactivation occurs in the primary tumor. In addition our finding that multiple metastatic deposits from individual patients share a pattern of LOH reinforces our hypothesis that the genetic event occurs prior to metastasis.

We did not detect an association between advanced local disease (defined as Gleason score 7 to 10, seminal vesicle involvement, margin positivity, or positive lymph nodes) and LOH at 12p12-13. In conjunction with the increased incidence of LOH in metastatic disease, the possibility is raised

that LOH at 12p12-13 could be an independent marker for disease progression. Additional followup will be required to address this question.

Previous studies have not detected 12p abnormalities in localized or metastatic prostate cancer. Several groups have examined localized and metastatic prostate cancer for LOH using microsatellite analysis, only two of which examined chromosome 12. Kunimi et al also used Southern blotting to examine 10 primary tumors, 4 lymph node metastasis, and 4 brain metastasis. 8p, 10p, 10q, 16q, 18q were found to demonstrate LOH in 50%, 55%, 30%, 60%, and 43% respectively. 12p was examined at one polymorphic marker (D12S16) in this study, the exact location of which is unknown and one brain metastasis demonstrated LOH at this marker.¹ Sakr et

al examined 19 primary tumors and lymph node metastases for evidence of LOH by PCR amplification of polymorphic repeats. Markers on 8p, 10q and 16q demonstrated LOH in 25%, 12% and 8% of metastatic samples, and 29%, 18% and 42% of primary tumors, respectively. Although no LOH was detected on 12p, they only examined one marker, F8VWF, which is approximately 9 cM telomeric from our region of interest.³ In summary only two of the previous LOH studies have examined 12p and neither examined a marker near our region of interest.

Comparative genomic hybridization is a second technique that identifies genomic loss. It has the advantage that it examines the entire genome. Visakorpi et al examined 31 primary and 9 locally recurrent prostate carcinomas and demonstrated genomic loss on 8p, 13q, 6q, 16q, 18q, and 9p.⁴ Nupponen et al demonstrated increased frequency of allelic loss in hormone refractory prostate carcinomas.⁶ An earlier study by Cher et al, also examining metastatic prostate cancers, demonstrated loss of 8p, 13q, 16q, 17p, and 10q.⁵ No CGH study to date has detected significant copy number loss at 12p, probably because this methodology lacks the resolution of microsatellite analysis and therefore smaller regions of chromosomal losses are not detected.

The homozygous deletion we identified at 12p12 to 13 contains a gene previously implicated in prostate carcinoma, p27/kip1.⁸ p27/kip1 is a member of the cip/kip family of cdk inhibitors, which also includes p21/cip1/waf1 and p57/kip2. Cip/kip family members accumulate in response to a variety of signals, including DNA damage, cell-cell contact, cytokine release, and hypoxia. By binding to cyclin-cdk complexes, cip/kip family members block Rb phosphorylation, prevent the release to E2F and, in doing so, inhibit the replicative machinery, which leads to cell cycle arrest.^{15,16}

Decreased expression of p27/kip1 has been implicated in prostate carcinoma.^{9,11-14} In general, decreased expression is associated with unfavorable tumor features and poor patient outcome. Guo et al and De Marzo et al demonstrated that decreased p27/kip1 staining correlated with high proliferative index and tumor grade.^{9,13} Multiple studies have demonstrated that absent or low expression in radical prostatectomy specimens correlated with decreased disease-free survival^{11,14} and even overall survival.¹² In contrast, only one published study has failed to demonstrate a correlation between decreased expression and PSA failure.¹⁰

Interestingly, while immunohistochemistry has demonstrated decreased p27/kip1 levels, mutations in the p27/kip1 gene are extremely rare in any malignancy. Ponce-Castaneda et al and Kawamata et al each examined a variety of tumor types, including 38 primary prostate carcinomas, and found only one silent mutation in a gastric carcinoma.^{17,18} The inability to identify mutational inactivation of the remaining p27/kip1 allele has raised the possibility that p27/kip1 is not a true tumor suppressor gene. An alternative hypothesis is that loss of one copy (haploinsufficiency) of p27/kip1 could provide a selective growth advantage and predisposes the cell to malignant transformation. This hypothesis is supported by new evidence that when challenged with carcinogens p27/kip1 heterozygous knockout mice are predisposed to malignant transformation in a variety of organ systems (not including prostate), and analysis of the tumors demonstrates the wild type p27/kip1 allele is neither mutated nor silenced.¹⁹

A more conventional hypothesis is that p27/kip1 is not the most important gene being inactivated at this locus. Other genes lie at 12p12 to 13 and clearly one of them could be more important in prostate tumorigenesis. ETV6/tel is a strong candidate since it lay within our homozygous deletion and has not been previously studied to our knowledge. ETV6/tel is a member of the ETS family of transcription factors, though its exact function is unknown. It was initially identified as a fusion protein to platelet-derived growth factor.²⁰

The ETV6/tel gene has been implicated as possible tumor suppressor gene in ALL because LOH has frequently been identified at this site.²¹ While ETV6/tel is expressed in a wide variety of tissues,²⁰ the only other malignancy in which ETV6/tel has been implicated is congenital fibrosarcoma through fusion of ETV6/tel to the NTRK3 neurotrophin-3 receptor gene.²² To our knowledge ETV6/tel has not been previously implicated in prostate cancer.

CONCLUSION

We have analyzed 60 primary prostatic carcinomas, 20 pelvic lymph node metastasis, and 19 distant metastasis. We have demonstrated that 1) 12p12-13 LOH is a prominent feature of primary prostate tumors, 2) multiple metastatic foci have an identical LOH pattern, 3) a strong association exists between 12p12-13 LOH and distant metastasis, and 4) no association exist between 12p12-13 LOH and advanced local disease. Our findings are consistent with the inactivation of a tumor suppressor gene, possibly p27/kip1, at 12p12-13 in the primary tumor and that this inactivation predisposes the tumor to metastasize.

REFERENCES

- Kunimi, K., Bergerheim, U. S., Larsson, I. L., Ekman, P. and Collins, V. P.: Allelotyping of human prostatic adenocarcinoma. *Genomics*, **11**: 530, 1991
- Bova, G. S., Carter, B. S., Bussemakers, M. J., Emi, M., Fujiwara, Y., Kyprianou, N., Jacobs, S. C., Robinson, J. C., Epstein, J. I., Walsh, P. C. and Isaacs, W. B.: Homozygous deletion and frequent allelic loss of chromosome 8p22 loci in human prostate cancer. *Cancer Res*, **53**: 3869, 1993
- Sakr, W. A., Macoska, J. A., Benson, P., Grignon, D. J., Wolman, S. R., Pontes, J. E. and Crissman, J. D.: Allelic loss in locally metastatic, multisampled prostate cancer. *Cancer Res*, **54**: 3273, 1994
- Visakorpi, T., Kallioniemi, A. H., Syvanen, A. C., Hyytinen, E. R., Karhu, R., Tammela, T., Isola, J. J. and Kallioniemi, O. P.: Genetic changes in primary and recurrent prostate cancer by comparative genomic hybridization. *Cancer Res*, **55**: 342, 1995
- Cher, M. L., Bova, G. S., Moore, D. H., Small, E. J., Carroll, P. R., Pin, S. S., Epstein, J. I., Isaacs, W. B. and Jensen, R. H.: Genetic alterations in untreated metastases and androgen-independent prostate cancer detected by comparative genomic hybridization and allelotyping. *Cancer Res*, **56**: 3091, 1996
- Nupponen, N. N., Kakkola, L., Koivisto, P. and Visakorpi, T.: Genetic alterations in hormone-refractory recurrent prostate carcinomas. *Am J Pathol*, **153**: 141, 1998
- Kibel, A. S., Schutte, M., Kern, S. E., Isaacs, W. B. and Bova, G. S.: Identification of 12p as a region of frequent deletion in advanced prostate cancer. *Cancer Res*, **58**: 5652, 1998
- Kibel, A. S., Freije, D., Isaacs, W. B. and Bova, G. S.: Deletion mapping at 12p12-13 in metastatic prostate cancer. *Genes Chromosomes Cancer*, **25**: 270, 1999
- Guo, Y., Sklar, G. N., Borkowski, A. and Kyprianou, N.: Loss of the cyclin-dependent kinase inhibitor p27(Kip1) protein in human prostate cancer correlates with tumor grade. *Clin Cancer Res*, **3**: 2269, 1997
- Cheville, J. C., Lloyd, R. V., Sebo, T. J., Cheng, L., Erickson, L., Bostwick, D. G., Lohse, C. M. and Wollan, P.: Expression of p27Kip1 in prostatic adenocarcinoma. *Mod Pathol*, **11**: 324, 1998
- Cordon-Cardo, C., Koff, A., Drobnjak, M., Capodiceci, P., Osman, I., Millard, S. S., Gaudin, P. B., Fazzari, M., Zhang, Z. F., Massague, J. and Scher, H. I.: Distinct altered patterns of p27KIP1 gene expression in benign prostatic hyperplasia and prostatic carcinoma [see comments]. *J Natl Cancer Inst*, **90**: 1284, 1998
- Cote, R. J., Shi, Y., Groshen, S., Feng, A. C., Cordon-Cardo, C., Skinner, D. and Lieskovsky, G.: Association of p27Kip1 levels with recurrence and survival in patients with stage C prostate carcinoma. *J Natl Cancer Inst*, **90**: 916, 1998
- De Marzo, A. M., Meeker, A. K., Epstein, J. I. and Coffey, D. S.:

- Prostate stem cell compartments: expression of the cell cycle inhibitor p27Kip1 in normal, hyperplastic, and neoplastic cells. *Am J Pathol*, 153: 911, 1998
14. Yang, R. M., Naitoh, J., Murphy, M., Wang, H. J., Phillipson, J., deKernion, J. B., Loda, M. and Reiter, R. E.: Low p27 expression predicts poor disease-free survival in patients with prostate cancer. *J Urol*, 159: 941, 1998
15. Sherr, C. J.: Cancer cell cycles. *Science*, 274: 1672, 1996
16. Clurman, B. E. and Porter, P.: New insights into the tumor suppression function of P27(kip1) [comment]. *Proc Natl Acad Sci USA*, 95: 15158, 1998
17. Ponce-Castaneda, M. V., Lee, M. H., Latres, E., Polyak, K., Lacombe, L., Montgomery, K., Mathew, S., Krauter, K., Sheinfeld, J. and Massague, J.: p27Kip1: chromosomal mapping to 12p12-12p13.1 and absence of mutations in human tumors. *Cancer Res*, 55: 1211, 1995
18. Kawamata, N., Morosetti, R., Miller, C. W., Park, D., Spirin, K. S., Nakamaki, T., Takeuchi, S., Hatta, Y., Simpson, J. and Wilczynski, S.: Molecular analysis of the cyclin-dependent kinase inhibitor gene p27/Kip1 in human malignancies. *Cancer Res*, 55: 2266, 1995
19. Fero, M. L., Randel, E., Gurley, K. E., Roberts, J. M. and Kemp, C. J.: The murine gene p27Kip1 is haplo-insufficient for tumour suppression. *Nature*, 396: 177, 1998
20. Golub, T. R., Barker, G. F., Lovett, M. and Gilliland, D. G.: Fusion of PDGF receptor beta to a novel ets-like gene, tel, in chronic myelomonocytic leukemia with t(5;12) chromosomal translocation. *Cell*, 77: 307, 1994
21. Baccichet, A. and Sinnett, D.: Frequent deletion of chromosome 12p12.3 in children with acute lymphoblastic leukaemia. *Br J Haematol*, 99: 107, 1997
22. Knezevich, S. R., McFadden, D. E., Tao, W., Lim, J. F. and Sorensen, P. H.: A novel ETV6-NTRK3 gene fusion in congenital fibrosarcoma. *Nat Genet*, 18: 184, 1998